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THE ACCURACY OF SOME RECENT RADAR ESTIMATES OF SURFACE PRECIPITATION

By T. W. HARROLD and C. A. NICHOLASS

Summary. Results of some recent quantitative radar measurements of precipitation, made in many geographical locations, are reviewed.

Reasons for variations in the measurements are discussed and methods for improving the accuracy of future measurements are considered.

Introduction. Ever since it was realized (30 years ago) that a radar could be used to detect the presence of precipitation, attempts have been made also to measure the quantity. However, although the qualitative use of radar is now well established, progress in the quantitative measurements of precipitation has been slow. This has been largely because of uncertainties in the accuracy of the measurements and the technical difficulties in processing the large amount of data obtained when echo intensity is measured at all points over an area under observation. Over the last decade progress has accelerated. In particular, many workers have investigated the accuracy of the radar-derived estimates of precipitation. The purpose of this article is to review the results of these experiments, in order to estimate the magnitude of the errors which have been obtained up to now and to suggest possible ways in which these errors might be reduced.

Firstly, it is worth while summarizing the advantages of this method of measuring precipitation compared with the only practical alternative of using some form of rain-gauge. The advantages are :

(a) the measurements are made :
  (1) over an area, (and most users, if not all, require measurements over an area),
  (2) in real-time, and
  (3) from a single location,
(b) snowfall can be measured and
(c) short-term forecasts of precipitation movement and intensity can be made.

The main disadvantages are:

(a) A possible reduction in accuracy compared with that of a rain-gauge. However, although this is certainly true for a point measurement, it may not be the case when measurements are extended to an area.

(b) Cost. However, the cost, including maintenance, of a radar installation may be similar to that of the network of telemetering rain-gauges which may be required for real-time information of comparable accuracy over an area.

The following sections will be concerned only with the accuracy of the system, but the advantages listed above should also be remembered since they are important when considering the practical use of radar as an alternative means of measuring precipitation.

Theory. Estimates of precipitation using radar depend on the relationship between measurements of the echo power reflected by the precipitation particles and the rate of precipitation.* Probert-Jones[1] and Borovikov *et alii*[2] have shown theoretically that, when precipitation uniformly fills the pulse volume,

$$\overline{P}_r = C_1\, C_2\, \frac{\sum D^6}{r^2}\, K,$$

where :

$\overline{P}_r$ is the average of the power P_r received from reflection from precipitation at range r, the average being over a sufficient number of radar pulses to ensure that the random fluctuations of the precipitation signal are averaged out (see for example Marshall and Hitschfeld[3]).

C_1 is a function of the radar parameters and can be evaluated by calibration procedures.

C_2 is a constant (for practical purposes) related to the dielectric properties of the precipitation particles.

$\sum D^6$ is the summation over unit volume of the sixth powers of the drop diameters D.

r is the range of the precipitation from the radar.

K is a measure of the attenuation of the radiation as it traverses the precipitation.

Probert-Jones, and other workers since, have shown that this equation is accurate to within the accuracy of the measurements of P_r.

Measurements of precipitation intensity are based on an empirical relationship of the form

$$\sum D^6 \equiv Z = AR^B,$$

where Z is defined as the radar reflectivity factor, A and B are empirically determined constants and R is the rate of precipitation.

Thus

$$\overline{P}_r = \frac{C_1\, C_2\, AK}{r^2}\, R^B .$$

This expression forms the basis of the use of radar for measuring precipitation.

* An alternative method is to relate the attenuation at a short wavelength to the rate of rainfall, but it seems unlikely that this is a practical means of estimating rainfall over an *area*. However, it may provide an additional means of calibration — see pages 201–203.

Possible sources of error.

The R–Z relationship. There is no unique drop-size distribution for a given rainfall rate, hence there is no unique R–Z relationship. The variations which occur have been summarized by, for example, Stout and Mueller[4] or Borovikov *et alii.*[2]

World-wide there are differences in excess of 500 per cent in R at a given Z. These large variations are associated primarily with differences in geographic locality. At a given locality the maximum difference is reduced to about 150 per cent. Thus, when estimating R from Z, it is preferable to use the R–Z relationship derived for that particular locality. A difficulty arises since such relationships are only known for a few localities in the world, but for practical applications this problem has been at least partially overcome by Cataneo,[5] who has shown that the relationship can be estimated from climatological data available as routine.

These variations show the approximate magnitude of the error in an estimate of instantaneous rate of rainfall at a point using a known value of Z. In most practical operations the rainfall amount over a period of time is required. In time integration much of the variation will be averaged out. For example, an analysis of drop-size distributions measured by Andrews in London (see for example Mason and Andrews[6]) indicates that when estimating the total rainfall from a storm using the average R–Z relationship for that locality (or Cataneo's estimate) the mean error is only 20 per cent. A similar analysis based on a small amount of the data published by Stout and Mueller[4] produced a mean error of about 18 per cent.

It was stated on page 193 that one of the major practical advantages of the radar method of measuring precipitation is that the measurements are made over an area. Very little is known about the variations in the R–Z relationship over an area. Apparently the only study in the literature is by Sims,[7] who measured drop-size distributions at three locations a few kilometres apart and found significant variations in one out of the three storms he studied. It is therefore possible that estimates of area rainfall based on area values of Z might be more accurate than is suggested by the studies of relationships at a point.

To summarize, the numerous studies of drop-size distributions show that rainfall at a point over a period of time can be estimated to within a few tens of per cent from known values of Z and that the error may be less for an area measurement.

It will be shown on pages 201–203 that the variability in the R–Z relationship may not determine an upper limit to the accuracy of a radar estimate of precipitation; it may be possible to calibrate the radar values using an independent estimate of R, for example that obtained using a rain-gauge.

Variation of Z with height. When radar is used, Z is measured within the pulse volume (determined by the beam width and pulse length). This value is used to estimate the precipitation at the surface. If Z varies with height then the measured Z differs from that at the ground, increasing the error in the estimate of R at the surface compared with that arising purely from R–Z variations. Figure 1 shows average profiles of Z for three types of precipitation. The data were obtained by Joss and Waldvogel[8] in Switzerland but are probably representative of precipitation in most parts of the world (see for

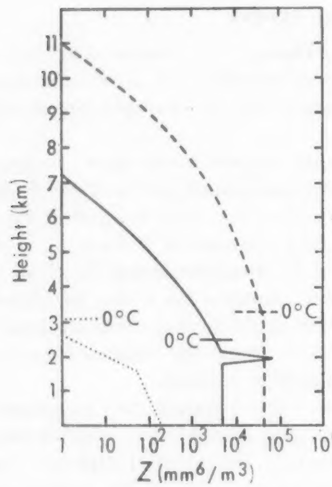

FIGURE 1—MEAN RADAR REFLECTIVITY PROFILES FOR THREE TYPES OF PRECIPITATION (after Joss and Waldvogel[8])

...... Drizzle ——— Widespread rain - - - Thunderstorms

example Harper[9], Donaldson[10]). Figure 2 shows the vertical extent of radar beams 2°, 1° and 0° wide as a function of range. From these figures it is clear that the errors in a surface estimate of precipitation will depend strongly on precipitation type, the vertical-beam width and the range of the measurement.

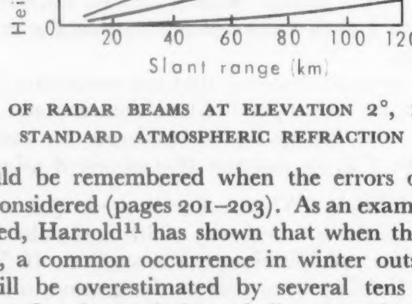

FIGURE 2—HEIGHT OF RADAR BEAMS AT ELEVATION 2°, 1° AND 0° ASSUMING STANDARD ATMOSPHERIC REFRACTION

These factors should be remembered when the errors obtained by various experimenters are considered (pages 201–203). As an example of the magnitude of the error involved, Harrold[11] has shown that when the radar beam intersects the 0°C level, a common occurrence in winter outside the tropics, the rate of rainfall will be overestimated by several tens of per cent unless corrections allowing for the variation of Z are made. In most cases the variation of Z near the 0°C level (the bright band — so called because the brightness of the echo on a range–height display is increased) constitutes the most marked variation of Z with height. However, there is evidence,

e.g. Bergeron,[12] that in regions of orographic precipitation considerable enhancement of precipitation rate, perhaps by a factor of two (e.g. Harrold[13]), occurs within the lowest kilometre of the atmosphere; such growth should be allowed for when radar is used to estimate the precipitation at the surface in these regions.

Attenuation. The signal intensity is attenuated as it traverses precipitation. This attenuation is a function of the wavelength of the radiation. It is negligible at 100 mm, but at 30 mm in rain it is so much greater that almost all workers agree that radars with this wavelength cannot be used operationally to measure quantitatively anything except light rainfall rates. However, in the past some experimental investigations have been made at this wavelength by including various devices (none of which can be used operationally) to correct for the attenuation. These experiments, some of which are included in pages 197–203, provide useful information on the accuracy which should be attained by a practical system, but must not be interpreted as endorsing the use of 30-mm radar as a practical quantitative instrument.

Variations in radar characteristics. The rainfall estimate is derived from quantitative measurements of the echo intensity. Any errors in the calibration of the radar system will lessen the accuracy of the rainfall estimate. Such errors can be large, even with an apparently well-calibrated radar. As a practical example, Wilson[14] showed there was a 15-dB error (equivalent to about a factor of six in rainfall rate) in the data he was analysing. Much smaller, but undetected, radar errors have probably occurred in almost all the experiments reported in the following pages. From a practical viewpoint it should be noted that the problem of large undetected errors is alleviated to some extent if an independent measurement of R is made somewhere within the area of radar coverage (pages 201–203).

Processing errors. In a practical operation errors will also arise if measurements are made other than continuously (sampling interval errors) and if echo intensity is quantized into discrete levels (quantizing errors). Neither of these aspects will be discussed specifically here since they are a function of the way in which the radar system is used, rather than inherent in the system itself.

Although some definite statements can be made about the probable magnitude of particular sources of error, it is not possible, *a priori,* to determine the overall accuracy of operational systems. Experimental results are required for this purpose. These are summarized in the following sections.

Experimental results.

Point and small-area comparisons. Table I summarizes some experiments using radar to measure the rainfall over small areas. Generally clusters of a few rain-gauges, about a hundred metres apart, were used to provide the standard with which to compare the radar estimate. The accuracy is expressed in terms of a mean percentage difference defined by

$$X = 100 \left| \frac{G-R}{G} \right|_m$$

TABLE I—COMPARISON OF RADAR AND GAUGE ESTIMATES OF PRECIPITATION AT A POINT OR OVER A SMALL AREA

Reference	Precipitation type	Radar λ	Radar φ	Radar ε	Range	Z–R relation A	Z–R relation B	Number of observations or of days	Period of summation	Differences between radar and rain-gauge estimates: X (a)	Y (a), (b)
		mm	degrees	degrees	km					per cent	per cent
Austin[25] (U.S.A.)	All	107	3	1	28	200	1·6	480	1-minute comparisons	35 (b)	42
Dimaksyan et alii[26] (U.S.S.R.)	All	30 (?)	3		32, 22, 12	Calibration from previous season.		56 days	5-minute comparisons (?)	18	
Joss et alii[17] (Switzerland)	All	47		90	0·2	250	1·6	18 days 14 days	Daily (1965)	44 (all rain) (b) 22 (totals >2 mm only)	71
	All	47		90	0·2	300 Derived from same season's drop-size data.	1·5	47 days 33 days	Daily (1967)	28 (b) 24 (totals >5 mm only)	43 34
						Function of rain type.		47 days	Daily (1967)	15 12 (totals >5 mm only)	
Woodley et alii[27] (U.S.A.)	Mostly thunder-storms	100	2	0·5	Gauges up to 87 km	300 Derived for same location from indepen-dent data.	1·4	50	Daily	51 all totals (b) 34 total >2 mm only	73 45

Notes : λ = wavelength φ = vertical beam width ε = beam elevation

(a) Different authors have expressed accuracies in different forms. Here we have, wherever possible, recomputed the accuracy in terms of

(1) mean percentage difference $X = 100\left|\dfrac{G-R}{G}\right|_m$,

and (2) root-mean-square percentage difference $Y = 100\left(\sum((G-R)/G)^2/(N-1)\right)^{\frac{1}{2}}$ where G is the rain-gauge estimate and R is the radar estimate of precipitation; this enables comparisons between experiments to be made.

(b) Values computed by the present authors from the published data.

where G is the gauge estimate and R is the radar estimate of the rain, and suffix m indicates the mean of the modulus over a series of comparisons, and/or in terms of a root-mean-square percentage difference defined as

$$Y = 100\left(\sum((G-R)/G)^2/(N-1)\right)^{\frac{1}{2}}.$$

Although the experiments were conducted in different parts of the world and used differing equipments, the results are reasonably consistent, the mean percentage difference varying between 18 and 35 per cent excluding some results from light rains, when a small absolute difference can produce a large percentage difference. The lower end of this range of accuracies is similar to the magnitude of the difference expected when R is estimated from Z using an R–Z relationship; this implies that errors from all other sources can be very small at times.

Experiments using radar to estimate the precipitation over small areas are comparatively easy to set up since a few rain-gauges provide a standard measure of rainfall which is accurate to a few per cent, provided the gauges are adequately exposed (e.g. Green[15]). However, radar is better suited to making measurements over an area, as point estimates using radar include two possible sources of error which might be reduced in an areal measurement. These are : (a) precipitation within the pulse volume may not fall in the rain-gauge(s) even if careful allowance is made for wind drifts; (b) R–Z variations may be less when averaged over an area than the variation at a point. Thus it is not possible to relate the accuracy of the point measurements directly to that which might be attained over an area.

Area comparisons. Table II summarizes some published results of radar measurements of area rainfall. Accuracies are again expressed in terms of mean percentage difference and root-mean-square percentage difference and also, as an addition compared with Table I, the density of rain-gauges which would be required to give the same accuracy in the rains measured. In this last method the authors assumed that the estimate using their complete experimental network was correct and then the area rainfall was computed from simulated sparser networks.

The table shows that accuracies vary widely — the mean percentage difference, for example, ranging between experimenters from 20 to 66. The reasons for some of the larger differences can sometimes be deduced from the published papers. Thus, Borovikov *et alii*[2] recognized that much of their error may be attributed to attenuation of the 32-mm wavelength and to possible day-to-day variations in the stability of the radar. The other experiments at 32-mm wavelength also will have some error due to attenuation.

Despite the expectation that radar measurements would be more accurate over an area than at a point, the results in Tables I and II reveal a tendency for errors over an area to be larger. This may not be a real effect since the experiments are not directly comparable, having been performed in different rains using different radars. On the other hand, it is possible that the apparent inaccuracies over an area reflect inadequacies in the area rain-gauge network, the rain-gauge errors in an area estimate being significant. In the experiments it was assumed that the network provided an accurate measure of the actual rainfall. Typically the density of gauges used has been about 1 gauge/25 km^2. According to the data of Golubev *et alii*[16] the accuracy of rainfall estimates using such a network is only about 30 per cent. This figure may not be

TABLE II—COMPARISON OF RADAR AND GAUGE ESTIMATES OF PRECIPITATION OVER AN AREA

Reference	Precipitation type	Radar λ	Radar φ	Radar ε	Max. range	Z–R relation A	Z–R relation B		Number of observations	Period of summation	Area	Number of gauges used	Differences X (a)	Differences Y (a)	Gauge density required to give the same accuracy
		mm	*degrees*	*degrees*	*km*						*km²*		*per cent*	*per cent*	*number per 10⁴ km²*
Aoyagi[18] (Japan)	Showers	32 (c)	1	1	50	200	1·6		28	10 minutes	638	27		57 (d)	103
	Continuous					200 100	1·6 1·4	(e)	66	10 minutes				34 (d)	78
	Showers					200	1·6		5	Storm			25 (b)		187
	Continuous					200 100	1·6 1·4	(e)	4	Storm			20 (b)		71
Borovikov *et alii*[2] (U.S.S.R.)	All	32 (f)	1		60	Matched radar and gauge totals over the season.			400	Storm	100	100	58 (b)	79 (b)	30
Jones[28] (U.S.A.)	Mostly thunderstorms	100		0?		Calibrated radar using one storm. Used three Z–R relations.			12	Storm	1000	49	66 (b)	105 (b)	—
						435 370 311	1·48 (thunderstorm) 1·31 (showers) 1·43 (continuous)		10	Storm			34 (b) (g)	45 (b) (g)	
Volynec *et alii*[29] (U.S.S.R.)	Snow	30			60	Matched 4-day totals over 100-km² area.			4	Storm	100		88 (i) (55 (h))		—
											200		59 (i) (53 (h))		
											400		52 (i) (57 (h))		
											800	53	39 (i)		
									99	3 hours			91 (77 (j))		
Wilson[14] (U.S.A.)	All	100	2		90	200	1·6		28	Storm	2590	168	58 (b)	99 (b)	20

Notes :
(a) and (b) as for Table I.
(c) Assumed attenuation 0·02R.
(d) Author's value for 'standard deviation'.
(e) $Z = 100R^{1\cdot4}$ used for diffuse echo on PPI.
(f) Attenuation apparently only allowed for inasmuch as seasonal calibration was a function of range.
(g) Excluding 2 cases with very large differences.
(h) Falls > 5 mm only.
(i) These values are 'mean square relative error'.
(j) Falls > 2 mm only.

representative of other localities, but it does emphasize the possibility that the 'standard' with which the radar estimate has been compared was itself in error. This was realized by Borovikov *et alii*[2] who used a network of 1 gauge/km^2 in order to obtain a reliable measure of the actual rainfall. Unfortunately any improvement in the radar estimate resulting from this network was masked by the other sources of error in their radar system which have been mentioned already.

The possible uncertainties in the accuracy of a rain-gauge based estimate of area rainfall emphasize that in any experimental comparison of radar and rain-gauge measurements as much attention should be devoted to the operation of the network of gauges as to the radar.

Possibilities of increasing the accuracy of radar estimates of precipitation by the use of additional calibration techniques. The majority of experimenters listed in Tables I and II used a fixed R–Z relationship in estimating R from the observed echo intensity. The study of R–Z relationship variations by Stout and Mueller[4] indicates that the accuracy of an estimate of R using a known Z is improved if (a) different relationships for different synoptic types are used or, to a smaller extent, if (b) the rainfall is classified into different types. The former stratification of data does not appear to have been investigated by means of radar, but Joss *et alii*[17] (Table I) and Aoyagi[18] (Table II) have verified that classification by rain type does improve the accuracy of a radar estimate of rainfall. Joss *et alii* found that the difference between the radar and gauge estimates was about halved.

Most of the error in a radar estimate of rainfall probably arises from variations in the R–Z relationship and in the radar calibrations. It has been suggested that the influence of these variations might be reduced if the radar estimates were calibrated directly against an independent estimate of the precipitation, the simplest technique being to match the radar and gauge totals over a point or small area and then apply the same calibration elsewhere over the area of radar coverage. Table III summarizes some results of experiments using this type of calibration. Wilson[19] and also the data of Borovikov *et alii*,[2] analysed for this purpose by the authors of this paper, confirm that a significant improvement can be obtained by this method upon results obtained using a fixed radar equation. Huff[20] investigated in some detail various possible calibrating techniques of which those listed in Table III are a representative sample. The accuracy of his results compares very favourably with the other radar estimates of rainfall over an area, but he concluded that it was preferable to improve direct measurements of rainfall from the radar echo presentation (viz. echo type) rather than use rain-gauge adjustment. He pointed out that, if calibration is made using a single gauge, the accuracy of the results may be less than that of the results obtained with the radar equation — if the gauge is not representative of the rainfall, in particular the drop-size distribution, over the area of interest. Huff's work indicates that further investigation of the use of gauge(s) to calibrate the radar estimate is needed before the potential value can be assessed fully; however, the other data in Table III suggest that, overall, the accuracy of the estimate of precipitation over an area is increased using this technique.

Russian workers, for example Berjulev *et alii*[21] have used a different method of calibrating the radar-derived precipitation field. They used the attenuation

TABLE III—COMPARISON OF RADAR AND GAUGE ESTIMATES USING ADDITIONAL CALIBRATION METHODS

Reference	Precipitation type	Radar λ	Radar φ	Max. range	Number of observations	Period of summation	Area	Calibration method	Differences X (a) Without calibration	Differences X (a) With calibration	Gauge density required to give the same accuracy
		mm	*degrees*	*km*					*per cent*	*per cent*	*number per 10^4 km^2*
Berjulev *et alii*[21] (U.S.S.R.)	All	32 and 8·6			22	Storm		Attenuation at 8·6-mm wave-length.		24 (n)	
Borovikov *et alii*[2] (U.S.S.R.)		As in Table II						Matched over 100-km^2 and used this calibration over 2 other 100-km^2 areas.	58 (b)	41 (b)	
Carlson[24] (Canada)	Snow	32	0·9	67	1	Storm	20 pts	Using one gauge value to calibrate.	—	21 (b) (46 (k))	
				67–117			36 pts		—	34	
				117–159			19 pts		—	36	
Huff[20] (U.S.A.)		10	2		15	Storms	500 km^2	25 gauges over adjacent 500 km^2.	—	30 (l)	25
					15	Storms	340 km^2	Used outer two-thirds of network.		12 (l)	150
					19	Storms	1000 km^2	Calibrating network: 1 gauge/580 km^2.		60	
					19	Storms	3100 km^2	1 gauge/250 km^2.		40	
					19	Storms		1 gauge/75 km^2.		20	
									r.m.s. error function (m)		
Wilson[19] (U.S.A.)		As in Table II						One central gauge matched to the radar total over surrounding 130 km^2.	1·96	1·59	
								Three calibrations using three gauges.		1·48	
								Mean of three-gauge calibrations.		1·53	

Notes : (a) and (b) as for Table I.
(k) 21 per cent was the mean percentage difference obtained by simulating calibrating gauges. 46 per cent was the greatest percentage difference obtained when the least representative gauge was used for the calibration.
(l) Median percentage difference.
(m) 'Root-mean-square error expressed as a factor in rainfall. The error is measured as the logarithmic difference between the estimated and actual rainfall.'[19]
(n) Root-mean-square error expressed as a percentage.

of 8·6-mm radiation along a fixed path as a measure of the mean rate of rainfall along that path. The accuracy of the calibration would depend on the variability of the relationship between attenuation (K) and rate of rainfall (R). This relationship, like the R–Z relationship, depends upon the drop-size distribution; but both theory and experiment show that the K–R dependence is less sensitive. Harrold[22] showed, experimentally, that the mean error in 23 estimates of storm rainfall along a 7-km path was 15 per cent. Since this technique would provide a calibration along a line, rather than at isolated points, it is possible that it would provide a more representative calibration for an area measurement than would the use of gauges. The results of Berjulev *et alii* (Table III) indicate that the method may well have practical applications.

Other possible means of increasing the accuracy of radar estimates of area precipitation. On pages 195–197 it was shown that, at low levels Z is sometimes a function of, height, particularly in orographic precipitation or when the bright band is low. Thus, a critical parameter in any measurement of precipitation is vertical-beam width. Greater accuracy is to be expected with narrower beams, and at shorter ranges. The effect of the vertical extent of the beam on precipitation estimates has been partially investigated by Wilson[23] and Carlson,[24] both of whom classified their results according to range. However, in both these experiments Z probably did not vary significantly at low levels, so their results may not be directly applicable to other studies. In general, the experimental results listed in the tables are influenced by an unknown amount by the vertical extent of the beam.

Other radar parameters are not as critical as the vertical-beam width in affecting the accuracy of radar estimates of precipitation. Provided that the problem of attenuation at 30-mm wavelength is avoided by use of a longer wavelength, very little improvement in accuracy would be expected if other parameters of most conventional weather radars were changed.

Discussion. This article has reviewed the results of some quantitative measurements of precipitation using radar. The measurements have been made by several workers in various parts of the world and over a wide range of meteorological conditions. The reported accuracies, compared with the rainfall measured by rain-gauges, vary widely. For example, in experiments using a conventional 100-mm weather radar with a 2° beam width, the average difference in the rainfall total obtained with radar and conventional techniques varies between experimenters over the range 30 to 100 per cent. Radar errors have been reduced by using one or more rain-gauge values to calibrate the radar, the point calibrations being applied over the area of radar coverage. For example in one experiment this technique almost halved the error in the radar estimates. Theoretical considerations, supported by a few experiments, suggest that further significant improvements should be obtainable especially if radars with narrower beams in the vertical are used, and/or quantitative measurements are limited to shorter ranges than has often been the case in past experiments.

Even without these modifications, in some parts of the world radar can already provide a better estimate of area rainfall than the existing rain-gauge network. Since it has the additional advantages that (a) the measurements are made in real-time, (b) snowfall can also be measured and (c) short-term fore-

casts can be made, it seems very probable that the radar technique will become an increasingly important operational method of measuring precipitation over areas. However, further experimental work is required before the full quantitative potential of a weather radar can be assessed. Work of this type is being undertaken as part of the Dee Weather Radar Project. This is a joint study by the Water Resources Board, the Dee and Clwyd River Authority, Plessey Radar Ltd and the Meteorological Office, to investigate the accuracy and operational problems of using weather radar to measure precipitation.

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CLASSIFIED CENTRAL-ENGLAND TEMPERATURES AND ENGLAND AND WALES RAINFALL

By N. E. DAVIS

Summary. Monthly mean central-England temperatures since 1698 are ranked for each month and divided into five equal classes (T_1 to T_5). A comparison between the class boundaries for each month over the whole period 1698 to 1970 and boundaries applying only to the period 1873 to 1970 show that the temperature of the summer months has not changed over the last 270 years but that the temperature of the winter months is higher in the more recent period, the greatest difference being about ½ degC in January.

Monthly rainfall totals for England and Wales since 1727 are also ranked for each month and divided into three equal classes (R_1 to R_3). A comparison between the class boundaries for each month over the whole period 1727 to 1970 and boundaries applying only to the period 1873 to 1970 also shows that the rainfall of the summer months has not changed over the last 240 years but that the winter months are wetter in the more recent period, the greatest difference being about ½ inch (13 mm), again in January.

An examination of the runs of warm and cold months shows that there is considerable temperature persistence in the summer and possibly in cold months in the spring, but no persistence in the autumn. Rainfall shows no persistence. Consideration of the numbers of T_1 or T_2 Januarys and Julys in 25-year periods shows that fluctuations in the temperature in central England have occurred with a period of about 70 years. The July fluctuations are mostly out of phase with the January fluctuations. The frequencies of rainfall classes R_1 or R_3 in 25-year periods show fluctuations in January also with a period of about 70 years in phase with the temperature fluctuations. In July the rainfall fluctuations have a period of about 50 years. The temperatures of the three winter months (December, January and February) have recently varied in phase with each other but out of phase with most other months.

Derivation of temperature data. Manley[1] published monthly mean temperatures for central England for the period 1698 to 1957 and has provided in an unpublished communication data for the period 1958 to 1965. The climatological branches of the Meteorological Office have estimated values for the last 5 years 1966 to 1970. The values over the whole period 1698–1970 for each month and each season (e.g. winter = December, January, February) were ranked and divided into five equal (as far as possible) classes with the lowest 20 per cent for each month being classified quintile 1, the next 20 per cent quintile 2 up to the highest 20 per cent quintile 5. For example the coldest January was January 1795 with a mean temperature of −3·1°C and the warmest was in 1916 with a mean temperature 7·5°C. There were 53 years with mean January temperatures 1·6°C or less, 57 years between 1·7°C and 2·8°C inclusive, 56 years between 2·9°C and 3·8°C inclusive, 55 years between 3·9°C and 4·7°C inclusive and 52 years with mean January temperatures greater than or equal to 4·8°C. It was not possible to make the number of years in each class more nearly equal than this as there were 5 Januarys with a mean temperature of 1·7°C and 6 with a mean temperature of 4·7°C.

Tables of the temperature data. Table I gives (a) the lower and upper boundaries for each quintile for each month and each season for the period 1698 to 1970 and (b) similar boundaries determined only from the period 1873 to 1970. Cases in which the differences between corresponding boundaries in the two periods are greater than or equal to 0·2 degC are marked with an asterisk*. Apart from the boundary between quintiles 1 and 2 in April and between quintiles 4 and 5 in summer, all the cases of such differences occur in the months October to March and in the autumn and winter seasons. The greatest differences occur in January in the boundaries between quintiles 1 and 2 and between 2 and 3 where they amount to 0·7 degC. This is equivalent to about 1·0 degC when the 98-year period 1873 to 1970 is compared with the earlier 175 years 1698 to 1872.

TABLE I—QUINTILE BOUNDARIES FOR PERIODS (a) 1698–1970 AND (b) 1873–1970

	December		January		February		March		April		May	
	a	b	a	b	a	b	a	b	a	b	a	b
	degrees Celsius											
T_5 lower	5·6	5·7	4·8	5·3*	5·7	5·7	6·7	6·8	9·0	9·0	12·3	12·2
T_4 upper	5·5	5·6	4·7	5·2*	5·6	5·6	6·6	6·7	8·9	8·9	12·2	12·1
lower	4·6	4·7	3·9	4·3*	4·6	4·8*	5·9	6·2*	8·4	8·3	11·5	11·5
T_3 upper	4·5	4·6	3·8	4·2*	4·5	4·7*	5·8	6·1*	8·3	8·2	11·4	11·4
lower	3·7	3·9*	2·9	3·6*	3·6	3·8*	5·0	5·2*	7·7	7·7	10·9	10·9
T_2 upper	3·6	3·8*	2·8	3·5*	3·5	3·7*	4·9	5·1*	7·6	7·6	10·8	10·8
lower	2·8	2·9	1·7	2·4*	2·4	2·6*	4·0	4·2*	6·9	7·2*	10·3	10·3
T_1 upper	2·7	2·8	1·6	2·3*	2·3	2·5*	3·9	4·1*	6·8	7·1*	10·2	10·2
	June		**July**		**August**		**September**		**October**		**November**	
	a	b	a	b	a	b	a	b	a	b	a	b
	degrees Celsius											
T_5 lower	15·3	15·2	17·0	17·1	16·5	16·5	14·4	14·4	10·6	10·7	7·2	7·4*
T_4 upper	15·2	15·1	16·9	17·0	16·4	16·4	14·3	14·3	10·5	10·6	7·1	7·3*
lower	14·6	14·5	16·1	16·2	15·8	15·8	13·7	13·7	9·9	10·2*	6·4	6·7*
T_3 upper	14·5	14·4	16·0	16·1	15·7	15·7	13·6	13·6	9·8	10·1*	6·3	6·6*
lower	14·1	14·1	15·6	15·5	15·4	15·3	13·0	13·0	9·4	9·5	5·7	6·1*
T_2 upper	14·0	14·0	15·5	15·4	15·3	15·2	12·9	12·9	9·3	9·4	5·6	6·0*
lower	13·5	13·5	15·1	15·0	14·7	14·6	12·5	12·5	8·5	8·8*	4·8	5·3*
T_1 upper	13·4	13·4	15·0	14·9	14·6	14·5	12·4	12·4	8·4	8·7*	4·7	5·2*

	Winter		Spring		Summer		Autumn	
	a	b	a	b	a	b	a	b
	degrees Celsius							
T_5 lower	4·9	5·2*	8·9	8·9	16·0	15·8*	10·4	10·5
T_4 upper	4·8	5·1*	8·8	8·8	15·9	15·7*	10·3	10·4
lower	4·2	4·5*	8·4	8·5	15·5	15·5	9·8	10·1*
T_3 upper	4·1	4·4*	8·3	8·4	15·4	15·4	9·7	10·0*
lower	3·5	4·0*	8·0	8·1	15·1	15·1	9·5	9·7*
T_2 upper	3·4	3·9*	7·9	8·0	15·0	15·0	9·4	9·6*
lower	2·7	3·0*	7·4	7·5	14·7	14·6	9·0	9·2*
T_1 upper	2·6	2·9*	7·3	7·4	14·6	14·5	8·9	9·1*

Cases in which the differences between corresponding boundaries in the two periods are greater than or equal to 0·2 degC are marked with an asterisk*.

The differences mean that the winter climate in central England has warmed as between the two periods 1698 to 1872 and 1873 to 1970 in such a way that in January the colder T_1T_2 classes are about a degree Celsius warmer in the latter period but that the warmer (T_4T_5) classes are only about half a degree warmer. On the other hand, the constant boundary values in the summer months show that the summer climate in central England has not apparently changed at all in the 273-year period. Any explanation of the winter warming must account for both of these facts.

Table II gives the quintile values for every month and season from 1698 to 1971. Modern years (i.e. years since 1873) which would be classified one quintile lower according to boundaries determined from the period 1873 to 1970 are marked with an asterisk*, those which would be classified one quintile higher are marked with a dagger†.

Table III gives the warmest and coldest months and seasons and Table IV the seasons with persistently very cold, average or very warm months, i.e. seasons with all 3 months quintiles 1, 3 or 5 respectively. As the probability of a quintile 1 month is 1/5, the probability of all 3 months of a particular season being quintile 1 is 1/125 so that over the 273 years some 2 or 3 of each of the seasons could be expected by chance to have all 3 months quintile 1.

Table IV shows that temperature persistence in summer and to a less extent in winter for both very cold (T_1) and very warm months (T_5) and for very cold months in spring, is such that the frequency of continuous cold or continuous warmth throughout a season is three or four times the chance expectancy.

From Table II the longest run of quintile 1 months is 8 from February to September 1816, the longest run of quintile 5 months is also 8 from March to October 1959, but the longest run of quintile 3 is only 6 months from October 1718 to March 1719. The longest run of quintile 1 or 2 months is 15 from November 1878 to January 1880 and of quintile 4 or 5 months is 13 from April 1947 to April 1948. There were no cold or very cold months for two years from October 1833 to September 1835 and no warm or very warm months for 22 months from January 1838 to October 1839. The expected lengths of these runs are 5, 9 and 16 months respectively and the chance of getting runs of lengths 8, 14 and 23 months respectively is about 1 per cent, 1 per cent and 3 per cent. Again, it may be concluded that there is significant persistence of temperature from one month to the next. Indeed by counting the frequencies of runs of various lengths it can be shown that the actual probability of getting a quintile 1 month following a quintile 1 month is nearly 1/3 (instead of the chance probability of 1/5) but the actual probability of getting a quintile 5 month following a quintile 1 month is only 1/9 (instead of the chance probability of 1/5).

The maximum number of years with the same quintile of temperature for a particular month is 5, occurring in October from 1764 to 1768 which were all quintile 2, in July from 1839 to 1843 which were all quintile 1 and in April from 1942 to 1946 which were all quintile 5. The chance expectancy in a period of 273 years is a run of 5 years. Temperature persistence for a particular month from one year to the next is thus no greater than chance.

Derivation of rainfall data. Monthly rainfall percentages (of the 1881–1915 normal) for England and Wales as a whole were given by Nicholas and Glasspoole[2] for the period 1727 to 1931. Similar monthly percentages have been given since in the annual issue of *British Rainfall.* These percentages were converted by the Meteorological Office to actual values in inches to the nearest tenth of an inch. The 244 values for each month from 1727 to 1970 were ranked and divided into three equal (as far as possible) classes with the lowest 33⅓ per cent for each month being classified tercile 1, the next 33⅓ per cent tercile 2 and the highest 33⅓ per cent tercile 3. For example the driest January was 1766 with a total of 0·3 in (1 in = 25·4 mm) and the wettest

TABLE II—QUINTILES OF MONTHLY AND SEASONAL CENTRAL-ENGLAND TEMPERATURES, 1698–1971

	J	F	M	A	M	J	J	A	S	O	N	D	W	S	S	A
1698	2	1	2	2	1	2	3	3	2	3	1	3		1	2	1
9	3	3	1	1	2	4	5	1	3	4	2	3	3	1	3	3
1700	4	2	1	5	4	1	1	2	2	2	2	3	3	3	1	2
1	3	2	1	1	2	3	5	4	4	1	4	3	2	1	5	2
2	4	5	4	1	2	1	1	4	4	3	1	2	5	1	2	3
3	2	3	3	3	1	1	2	3	1	1	5	4	2	2	1	1
4	2	2	3	4	2	2	4	4	1	2	4	3	3	3	4	1
5	2	2	1	2	1	1	2	5	1	2	1	4	2	1	2	1
6	2	3	4	4	4	5	3	4	1	5	3	4	3	4	4	3
7	3	2	3	3	3	5	5	4	4	1	4	2	3	3	5	3
8	5	3	5	5	2	2	1	5	5	1	5	2	4	5	3	4
9	1	1	1	4	4	3	3	3	3	4	5	4	1	3	3	5
1710	2	2	4	1	4	3	1	3	3	3	5	5	3	3	2	4
1	5	1	3	5	3	5	1	2	2	3	5	2	5	4	3	4
2	2	3	3	3	3	4	4	1	2	3	3	5	3	3	3	2
3	2	4	1	1	1	1	1	2	4	3	1	3	4	1	1	3
4	4	4	3	2	1	3	5	1	2	5	3	3	4	2	4	4
5	4	4	5	5	3	2	1	2	4	5	4	1	4	5	1	5
6	1	2	2	4	2	2	3	2	1	3	2	2	1	3	2	2
7	4	2	2	2	1	2	1	2	3	3	2	4	2	1	1	2
8	1	2	3	3	3	3	5	5	5	3	3	3	2	3	5	4
9	3	3	3	1	4	3	5	5	4	2	3	2	3	2	5	3
1720	4	3	1	2	3	1	4	1	3	1	3	5	3	2	1	2
1	5	1	1	3	1	2	1	3	4	2	3	3	3	1	1	3
2	4	4	4	3	2	2	1	2	3	4	5	3	4	3	1	5
3	1	3	5	4	4	4	2	3	3	5	5	5	2	4	3	5
4	5	3	2	2	3	5	1	4	5	2	2	2	5	2	4	2
5	4	2	3	3	2	1	1	1	2	3	4	3	3	3	1	3
6	1	3	2	4	5	5	3	3	5	4	3	1	2	4	5	4
7	4	4	3	5	5	4	4	5	5	5	1	2	3	5	5	4
8	4	2	5	3	5	5	4	4	2	2	5	1	2	5	5	3
9	1	1	1	2	2	4	4	3	5	4	5	4	1	1	4	5
1730	4	4	4	4	5	2	2	4	5	5	5	2	4	5	3	5
1	2	1	4	1	4	5	4	5	5	5	5	4	1	3	5	5
2	2	5	4	4	3	4	3	5	5	5	3	1	4	4	4	5
3	5	5	4	5	3	4	5	4	2	2	4	5	5	5	5	2
4	4	5	5	5	3	3	4	4	3	1	3	3	5	5	4	2
5	4	3	3	4	3	1	1	4	4	4	3	4	3	4	2	4
6	5	2	5	4	2	5	4	5	5	4	4	5	5	4	5	5
7	5	3	4	4	5	5	5	1	4	2	3	4	5	5	4	3
8	4	4	3	5	3	3	4	4	2	4	3	5	4	5	4	3
9	4	5	3	1	4	4	3	2	3	3	1	2	5	4	3	1
1740	1	1	1	1	1	1	2	2	4	1	1	1	1	1	1	1
1	2	3	2	2	1	4	3	5	5	5	5	3	2	1	4	5
2	2	3	2	1	2	4	3	4	1	2	1	1	2	1	4	1
3	3	4	3	1	5	5	1	5	4	2	5	4	2	3	4	5
4	1	2	2	1	2	3	4	3	2	3	4	2	2	2	3	3
5	3	1	2	2	3	1	4	2	4	4	3	1	2	2	1	4
6	2	1	1	2	5	3	3	4	4	1	1	4	1	2	3	1
7	3	5	1	3	4	4	4	5	5	3	4	4	4	2	5	4
8	2	1	1	1	2	4	2	4	4	2	4	5	2	1	3	4
9	5	3	3	1	5	1	5	3	4	4	4	4	3	3	2	4
1750	4	5	5	3	2	3	5	2	5	2	1	3	5	5	4	3
1	4	1	4	2	1	4	2	1	2	1	1	2	2	2	2	1
2	3	2	3	1	2	4	3	3	4	5	4	3	2	2	3	4
3	2	3	4	2	4	4	2	3	3	4	1	3	2	4	3	2
4	3	2	1	1	4	2	1	3	4	4	3	2	3	2	2	4
5	2	1	1	5	1	5	1	1	3	1	1	3	1	2	3	1
6	4	4	4	1	1	2	4	2	3	3	1	2	4	1	2	2
7	1	3	2	3	2	2	5	2	3	1	4	2	1	2	4	3
8	2	3	3	2	5	4	1	4	1	1	3	3	2	4	3	1
9	5	5	4	4	4	4	5	4	3	5	2	1	5	5	5	4
1760	2	3	4	5	4	4	4	4	5	2	3	5	2	5	5	4
1	5	5	5	5	4	3	3	4	4	3	3	3	5	5	4	4
2	4	3	1	5	5	5	5	2	3	1	1	2	4	5	5	1
3	1	4	3	4	1	4	2	2	3	1	3	5	1	3	3	2
4	3	3	1	2	4	2	4	2	2	2	1	2	4	2	3	1
5	5	1	3	2	3	2	3	2	3	2	1	1	2	3	2	1
6	1	1	2	3	1	2	3	5	3	2	5	2	1	1	3	4
7	1	4	2	2	1	1	1	4	4	2	4	2	2	1	1	4
8	1	4	2	3	4	2	3	4	1	2	2	4	2	3	3	1
9	2	2	3	3	3	1	4	2	2	1	3	4	2	3	2	1
1770	3	4	1	1	1	1	2	4	4	2	2	2	4	1	2	2
1	1	2	1	1	4	3	3	1	1	2	3	5	1	1	2	2
2	1	1	2	1	1	5	4	4	3	5	5	4	2	1	5	5
3	4	2	4	3	2	4	3	4	1	4	2	3	3	4	4	2
4	1	3	4	4	3	4	4	4	2	4	2	2	1	4	4	2
5	4	5	4	5	5	5	4	4	4	2	2	3	4	5	5	3
6	1	3	4	5	2	3	4	2	2	4	3	3	1	5	3	4
7	2	1	5	2	4	2	2	4	5	4	4	1	1	4	2	5
8	2	2	2	3	2	5	5	5	1	1	4	5	1	2	5	1
9	3	5	5	5	4	3	5	5	5	5	3	2	5	5	5	5
1780	1	1	5	1	5	3	4	5	5	2	1	2	1	5	5	3
1	2	4	4	5	4	5	5	5	4	5	4	4	2	5	5	5
2	5	1	2	1	1	4	3	1	3	1	1	2	4	1	2	1
3	3	2	1	5	2	4	5	4	2	3	3	1	2	2	5	3
4	1	1	1	1	5	2	2	1	5	1	2	1	1	1	1	2
5	3	1	1	4	5	5	4	1	3	2	2	2	1	1	3	2
6	2	2	1	3	3	5	1	2	1	1	1	2	2	1	3	1
7	3	5	5	2	4	2	3	3	2	3	1	3	3	4	3	2
8	4	3	1	5	5	5	3	4	3	3	3	1	3	5	4	4
9	1	4	1	2	5	2	2	5	3	2	1	5	1	1	3	1
1790	4	5	4	1	4	4	1	3	1	4	3	3	5	3	2	3
1	4	4	4	5	2	4	2	4	4	2	3	1	4	5	3	3
2	2	3	4	5	1	1	2	5	1	2	5	3	1	4	3	2
3	2	4	2	1	3	2	5	2	1	5	3	4	3	1	3	3
4	2	5	5	5	3	5	5	3	2	3	3	3	4	5	5	2
5	1	1	1	3	3	1	2	5	5	5	1	5	1	2	2	5
6	5	4	2	5	2	2	1	4	5	1	1	1	5	3	2	2
7	3	4	2	2	3	2	5	4	2	1	1	4	1	2	4	1
8	3	3	3	5	5	5	4	4	3	4	1	1	3	5	5	2
9	2	2	1	1	1	3	2	1	2	1	2	1	1	1	1	1
1800	2	1	2	5	5	2	5	5	4	2	2	2	1	4	5	3
1	4	4	5	3	4	4	4	5	4	4	2	1	4	5	5	3
2	1	3	3	4	2	2	1	5	4	4	2	2	1	4	2	3
3	2	2	4	5	2	2	5	4	1	2	2	3	2	4	4	1
4	5	2	2	2	5	5	3	3	4	5	4	1	4	3	4	5
5	2	3	4	3	1	1	3	4	5	1	2	2	2	3	3	2
6	4	3	3	1	4	4	2	4	3	5	5	5	3	3	4	5
7	2	3	1	3	4	3	5	5	1	5	1	1	4	2	5	1
8	2	2	1	1	5	4	5	5	2	1	3	1	1	2	5	1
9	2	5	4	1	5	2	2	2	2	4	1	3	2	3	1	2
1810	2	2	2	3	1	4	2	1	4	3	2	2	2	2	2	3
1	1	4	5	4	5	3	4	1	4	5	5	2	2	5	2	5
2	2	4	1	1	3	1	1	1	3	2	2	1	3	1	1	2
3	2	5	5	2	4	2	1	1	2	1	1	2	2	4	1	1
4	1	1	1	5	1	1	3	2	2	1	1	3	1	1	1	1
5	1	5	5	3	5	3	1	2	3	4	1	1	3	5	2	2
6	2	1	1	1	1	1	1	1	1	4	1	2	1	1	1	1
7	4	5	3	2	1	4	1	1	3	1	5	1	4	1	1	3
8	4	2	2	2	3	5	5	2	3	5	5	2	2	2	5	5
9	4	3	5	4	4	1	4	5	3	2	1	1	3	5	4	1
1820	1	2	2	4	3	2	3	2	1	1	2	4	1	3	2	1
1	3	1	3	5	1	1	1	4	5	4	5	5	3	3	1	5
2	4	5	5	3	5	5	3	2	1	5	5	1	5	5	5	5
3	1	2	3	1	4	1	1	1	2	1	4	4	1	3	1	2
4	4	4	2	2	2	1	3	2	4	3	5	4	4	2	2	4
5	3	3	3	5	4	3	5	4	5	5	2	4	4	4	4	5
6	1	5	4	4	3	5	5	5	3	5	1	5	3	4	5	3
7	2	1	4	4	4	3	4	2	4	5	4	5	2	5	3	5
8	5	4	4	3	5	5	3	2	4	4	5	5	5	5	4	5
9	1	3	2	1	5	4	2	1	1	1	1	1	3	2	2	1
1830	1	1	5	4	4	1	4	1	1	4	4	1	1	5	1	3
1	1	4	5	5	4	5	4	5	4	5	2	5	2	5	5	5
2	3	2	3	4	3	4	3	3	3	5	3	4	3	4	4	4
3	1	4	1	3	5	4	3	1	1	4	4	5	3	5	2	3
4	5	4	5	3	5	5	4	4	4	5	4	5	5	5	5	5
5	3	5	3	4	3	4	4	5	3	2	4	2	4	4	5	3
6	3	2	3	2	3	5	2	1	1	2	2	3	2	3	3	1
7	2	4	1	1	1	5	4	3	2	4	2	4	3	1	5	2
8	1	1	2	1	2	3	3	2	2	3	1	3	1	1	2	2
9	2	3	2	1	1	3	1	1	1	2	5	3	3	1	1	3

TABLE II—*continued*

	J	F	M	A	M	J	J	A	S	O	N	D	W	S	S	A
1840	4	3	1	5	3	3	1	4	1	1	3	1	3	3	1	1
1	1	2	5	3	5	1	1	1	3	2	2	3	1	5	1	2
2	1	3	4	3	3	5	1	5	3	1	2	5	2	4	4	1
3	4	1	3	4	2	1	1	2	5	1	3	5	4	3	1	2
4	3	1	2	5	2	4	2	1	3	2	3	1	4	4	1	3
5	3	1	1	4	1	4	1	1	1	3	4	4	1	1	1	2
6	5	5	4	3	5	5	4	5	5	3	4	1	5	4	5	5
7	2	2	3	1	5	2	5	2	1	5	5	4	1	3	4	4
8	1	5	4	3	5	3	3	1	2	3	3	5	3	5	1	2
9	4	5	4	1	4	2	2	3	3	2	4	2	5	3	2	3
1850	1	5	2	5	1	5	4	1	1	1	5	4	3	2	3	2
1	5	4	3	2	2	3	1	3	2	5	1	4	5	2	2	1
2	5	4	3	3	2	1	5	4	2	1	5	5	4	3	4	3
3	5	1	1	2	3	3	1	2	1	4	2	1	4	1	1	2
4	3	3	5	5	2	1	2	2	5	3	2	4	2	4	1	3
5	2	1	1	2	1	1	4	3	3	3	2	1	1	1	3	2
6	3	4	2	3	1	2	2	5	2	5	2	3	3	1	3	2
7	2	3	3	2	3	5	4	5	5	5	4	5	3	3	5	5
8	3	1	2	3	2	5	1	4	5	3	1	4	4	2	4	3
9	5	5	5	2	4	4	5	4	2	3	2	1	5	4	5	2
1860	3	1	2	1	4	1	1	1	1	3	1	1	1	2	1	1
1	2	4	4	2	2	4	1	4	3	5	1	3	2	3	3	3
2	4	4	3	4	5	1	1	1	3	4	1	5	4	5	1	1
3	5	5	4	4	2	2	2	3	1	4	5	5	5	4	2	3
4	2	1	2	4	5	2	2	1	3	3	2	3	3	4	1	3
5	2	1	1	5	5	5	4	2	5	3	4	5	2	4	4	5
6	5	3	2	4	1	5	2	2	2	5	4	5	5	2	3	4
7	1	5	1	3	3	3	1	4	3	2	2	2	4	2	3	2
8	4	5	5	4	5	5	5	5	4	1	2	5	4	5	5	2
9	5	5	1	5	1	1	5	3	5	3	3	2	5	2	3	4
1870	3	2	2	5	4	4	5	3	2	3	1	1	2	4	5	2
1	1	5	5	4	3	1	2	5	2	3	1	2	1	5	3	1
2	5	5	5	3	1	3	5	2	3	1	4	4	5	3	4	3
3	5	1	3	3	1	3	4	3	1	2*	3	4	3	2	3	1
4	5	3	5*	5	1	2	5	2	3	4	2	1	5*	4	3	4*
5	5	1	3*	4	5	3	1	4	5	2	2	3	2*	4	3	4*
6	3*	4	2	3	1	3	5	5	2	5	3	5	3	1	5	4
7	5	5	2	2*	1	4†	1	2	1	2	4	4	5	1	3	2
8	4	4	3	4	4	4	4	4	3	4	1	1	5*	4	4†	2*
9	1	2	2	1	1	1	1	1	2	2	1	1	1	1	1	1
1880	1	5	4	3	2	2	2†	4	5	1	2	4	1	3	3	2*
1	1	2	3	2	4	2	4	1	2	1	5	3	1	3	1†	3*
2	5*	5	5	4	4	1	2	2	1	4*	3*	3	5*	5	1	2
3	4	5	1	3	2	2	1	2†	3	3	3*	4*	4	1	1†	3*
4	5	4	4	2	3	3	4	5	5	3*	2	3	5	3	4†	3
5	3*	5	2	3	1	2	4	1	1	1	3*	3*	4*	1	1†	1
6	2*	1	2	2	2	2	3	4	3	5	4*	1	1	2*	3	5
7	2	3	1	1	1	5	5	3	1	1	1	1	2*	1	5	1
8	3*	1	1	1	2	1	1	1	1	1	5	4	1	1	1	2
9	3*	2	2	2*	5	5	2	2	2	2*	4	2	3*	3	3	2
1890	5	2	4	2*	4	2	1	1	5	3*	3*	1	3	3	1	4*
1	1	3	1	1	1	4	2	1	4	3*	2	3	1	1	1†	3
2	2*	3*	1	2	4	1	1	2	1	1	4*	1	2	1	1	1
3	2*	4*	5	5	5	5	4	5	2	4*	2*	4	2*	5	5	2
4	3*	4	5*	5	1	2	3	1	1	2	5	4	4*	4	1	3*
5	1	1	3*	3	5	4	2	4	5	1	5	3	1	4	3	4*
6	5*	4*	5*	5	4	5	4	1	3	1	1	3	4*	5	4	1
7	1	5	4	2*	1	4	4	4	1	4*	5	4	3*	2	4†	4*
8	5	4	2	4	1	2	2	5	5	5	5*	5	5	2	3	5
9	5*	4	3*	3	1	5	5	5	3	2	5	1	5	2	5	4
1900	4	2	1	3†	2	4	5	2	3	3	5*	5	2	2*	4†	4
1	3*	1	2*	4	4	2	5	3	4	3	2*	2	4*	3	4†	3*
2	4	1	5*	2	1	2	1	1	2	3	4	4*	2	2	1	4*
3	4*	5	5	1	3	1	2	1	3	4	4*	2	5	3	1	4*
4	4*	2	2	4	3	1	5	2	2	3	2*	3*	3*	3*	3	2
5	3	4	5	2	2	4	5	2	1	1	2*	4	3	3	4	1
6	5	2	3*	2	2	3	3	5	4	5	5*	2	4*	2	4	5
7	3	2	4	2	2	1	1	1	3	3	4*	4*	2	3	1	4*
8	2	4	2	1	5	3	3	1†	2	5	5	3	3	2	2	5
9	3*	2	1	4	3	1	1	3	1	4	2*	3	2	2	1	2*
1910	3*	4	4*	2	3	4	1	2	2	5*	1	5	4*	3	2	1
1	3	4	3	2	5	3†	5	5	4	2	3	5	5*	4	5	4*
2	4	5	4	4	2	4*	1	1	1	1	3	5	5*	5	1	1
3	4	4	4	3	3	3	1	2	4	5	5	4	5	4	2	5
4	3	5	4*	5	2	3†	3	4	3	4	4	4*	5	5	3	4
5	4*	3	3	3	2	3	1	2†	3	2	1	4	4*	3*	2	1
6	5	3	1	3	4	1	2	4	3	5*	4	1	5	2	1	4
7	1	1	1	1	5	4†	4*	2†	4	1	5	1	1	1	4	4*
8	3	5	3	1	5	1	2	4	1	2	2	5	4*	4	2	1
9	3*	1	1	2*	5	3	1	3	2	1	1	4	3*	3	2	1
1920	5*	5	5	3	4	3	1	1	3	4	4	3	5	5	1	4
1	5	4	5	3	4	4	5	3	4	5	1	5	5	5	5	5*
2	3	3	2	1	5	2	1	1	1	1	3*	5	5*	2	1	1
3	5	4	4	2	1	1	5	2	2	3	1	3*	5	2	3	1
4	4	2	2*	2*	4	2	2	1	3	4*	4	5	3*	2	1	4
5	5	4	2	2	4	4	4	3	1	4	1	2*	5	3*	4	1
6	4	5	4	5	1	2	5	4	5	1	3*	3	4	4	4	2
7	4	3	5	3	3	1	3	3	2	4	3	1	4*	4	2	3
8	5*	5	4	4	3	1	4*	2†	2	4*	5	2	4*	4	2	4
9	1	1	4	1	3	1	3	3	5	3	4	5	1	3	2	5
1930	5	2	3	3†	2	5	2	3	3	4	3	3	4	3	3	4
1	3*	3	2	3	3	3	2	1	1	2	5	4	3*	2	2	2
2	5	2	2	2*	2	3	4*	5	2	2	4*	5	4	2*	4	2
3	2*	3	5	4	4†	5	5	5	5	4*	2	1	3	5	5	4
4	4*	3	2	3	3	4	5	3	5	5*	3	5	2	3	5	5*
5	4	5	4	3	1	4	5	5	3	3	4	2*	5	3	5	4*
6	3	2	5	1	4	4	2	4	5	3*	2	4	3	3	3	4*
7	5*	4	1	5	4†	3	4*	5	3	4	2*	2	5	3	4	3*
8	5	4	5	2	2	3	2	4	4	4	5	3	4	5	3	5
9	4*	4	3	4	3	3	2†	4	4	1	5	2	4	4	3	5*
1940	1	2	4*	4	5	5	2	3	2	3	4	3*	1	5	4	4*
1	1	2	3*	1	1	4	5	2	5	4	4*	5*	1	1	4	5
2	1	1	3	5	3	3	2†	5	3	4	2*	5	1	4*	4	3
3	5*	5	4	5	4	3	4	4	3	5*	3	2	5	5	4	4
4	5	3*	3	5	3	2	4	5	2	2	3	2	4*	5	4	2
5	1	5	5	5	4†	4	4	4	5	5	5*	4	3*	5	4	5
6	2	5	3*	5	2	1	4	2	4	3	5	2	4	4	2	5
7	2*	1	1	4	5	5	5*	5	5	5*	5*	4	1	4	5	5
8	5	4*	5	5	3	2	3	2	4	4*	5*	5	5*	5	2	5*
9	5	5	3*	5	3	5	5	5	5	5	4*	5	5	4	5	5
1950	4*	4	5	2	3	5	3	3	2	3	3*	1	5*	4	4†	2
1	4*	3*	2*	1	1	2	4	2	4	3*	5	4	2*	1	3	5
2	2	2	4	5	5	3	4	4	1	2	1	2*	3*	5	4	1
3	3*	3	3	2	5	3	2†	4	4	3	5	5	3*	4	3	5
4	3*	2	3	2	3	1	1	1†	2	5	4	5	3	3	1	5
5	2	1	1	5	1	2	5	5	4	2	4	4	3*	2*	5	4
6	3	1	4	2*	4	1	3	1	4	3*	3*	5	2*	3	1	4*
7	5	4	5	4	2	4†	4	3	2	5	4*	3	5	5	4	4*
8	3*	4*	1	2	3	3	3	4	5	5	4*	4	4*	2*	3	5
9	1	3	5	5	5	5	5	5	5	5	4	5	3*	5	5	5
1960	3	3	4	4	5	5	2	2	3	4	5	3	4	5	3	4
1	3	5	5	5	3	3	2	3	5	5	3*	1	4	5	2	5
2	4	3	1	3	2	2	2	1	2	4	2	1	3*	1	1	3*
3	1	1	4*	4	2	4	2	1	2	5	5	1	1	4*	2	5
4	3*	4*	2	4	5	2	4*	3	4	2	5	3*	3*	4	3	4
5	3*	2	3	3	4	3	1	3	1	5	1	3	3*	3	1†	2
6	2	5	4	2	3	4†	1	2	4	4	2	4	4*	4	2	4*
7	4	4	5	3	2	3	4	3	4	5	2*	3	5*	4	4	4*
8	4*	1	4	3	1	4	2	3	4	5	4*	2	2	3	3	5
9	5	1	1	2	3	2	4	4	3	5	2	2*	2*	1	4	5
1970	3	2	1	1	5	5	2	4	5	5	5	3	2	2	4†	5
1	4	4*	3*	3	4	1	4	4	4	5	3	5	4*	3	3	5

Note: Modern years (since 1873) which would be classified one quintile lower according to boundaries determined from the period 1873 to 1970 are marked with an asterisk*; those which would be classified one quintile higher are marked with a dagger†.

TABLE III—WARMEST AND COLDEST MONTHS AND SEASONS IN PERIOD 1698 TO 1970

	J	F	M	A	M	J	J	A	S	O	N	D
Warmest months												
Year	1916	1779	1957	1865	1833	1846	1783	1947	1729	1969	1818	1934
Temperature (°C)	7·5	7·9	9·2	10·6	15·1	18·2	18·8	18·6	16·6	13·1	9·5	8·1
Coldest months												
Year(s)	1795	1947	1785	1701 1837	1698	1909 1916	1816	1912	1807	1740	1782	1890
Temperature (°C)	−3·1	−1·9	1·2	4·7	8·3	11·8	13·4	12·9	10·5	5·3	2·3	−0·8

	Winter	Spring	Summer	Autumn
Warmest seasons				
Year(s)	1869	1893	1826	1730 1731
Temperature (°C)	6·8	10·2	17·6	11·8
Coldest seasons				
Year(s)	1740	1837	1725	1740 1786
Temperature (°C)	−0·4	5·6	13·1	7·5

TABLE IV—SEASONS WITH ALL 3 MONTHS OF QUINTILES (a) 1, (b) 3 OR (c) 5

	Winter	Spring	Summer	Autumn
(a) All 3 months quintile 1				
	1729	1713	1812	1786
	1766	1740	1816	1829
	1784	1770	1823	1887
	1830	1799	1841	
	1917	1816	1862	
	1963	1837	1879	
		1887	1888	
		1891	1907	
			1954	
(b) All 3 months quintile 3				
	1699	1707	1709	1788
	1719	1712		
	1931	1718		
		1769		
(c) All 3 months quintile 5				
	1863	1893	1778	1730
	1869	1959	1781	1731
	1877		1826	1741
	1943		1868	1947
	1949		1899	1970
			1933	
			1947	
			1949	
			1959	

1948 with a total of 7·0 in. There were 83 Januarys with England and Wales rainfall totals 2·2 in or less, 80 between 2·3 and 3·5 in and 81 with 3·6 in or more. It was not possible to make the number of years in each class more nearly equal than this as there were 6 years with a total of 2·2 in.

Tables of the rainfall data. Table V gives (a) the upper and lower boundaries of each tercile for each month and each season for the period 1727 to 1970 and (b) similar boundaries determined only from the period 1873 to 1970. Cases in which differences between the corresponding boundaries in the two periods are greater than or equal to 0·2 in are marked with an asterisk*. Apart from the boundary between terciles 1 and 2 in

TABLE V—TERCILE BOUNDARIES FOR ENGLAND AND WALES RAINFALL FOR PERIODS (a) 1727–1970 AND (b) 1873–1970

	December		January		February		March		April		May	
	a	b	a	b	a	b	a	b	a	b	a	b
						inches						
R_3 lower	4·0	4·2*	3·6	4·1*	3·1	3·3*	2·8	2·8	2·7	2·7	2·8	2·8
R_2 upper	3·9	4·1*	3·5	4·0*	3·0	3·2*	2·7	2·7	2·6	2·6	2·7	2·7
lower	2·7	3·1*	2·3	2·8*	1·9	1·9	1·7	1·8	1·8	1·9	1·9	2·0
R_1 upper	2·6	3·0*	2·2	2·7*	1·8	1·8	1·6	1·7	1·7	1·8	1·8	1·9
	June		July		August		September		October		November	
	a	b	a	b	a	b	a	b	a	b	a	b
						inches						
R_3 lower	3·1	3·0	3·8	3·8	3·8	3·9	3·8	3·5*	4·3	4·4	4·0	4·4*
R_2 upper	3·0	2·9	3·7	3·7	3·7	3·8	3·7	3·4*	4·2	4·3	3·9	4·3*
lower	2·0	1·9	2·5	2·5	2·7	2·9*	2·4	2·3	2·9	3·0	2·8	2·9
R_1 upper	1·9	1·8	2·4	2·4	2·6	2·7*	2·3	2·2	2·8	2·9	2·7	2·8

	Winter		Spring		Summer		Autumn	
	a	b	a	b	a	b	a	b
				inches				
R_3 lower	9·9	10·9*	7·5	7·7*	9·9	10·0	11·1	12·0*
R_2 upper	9·8	10·8*	7·4	7·6*	9·8	9·9	11·0	11·9*
lower	7·7	8·5*	6·2	6·4*	7·8	7·6*	9·1	9·2
R_1 upper	7·6	8·4*	6·1	6·3*	7·7	7·5*	9·0	9·1

Cases in which differences between the corresponding boundaries in the two periods are greater than or equal to 0·2 in are marked with an asterisk*.

August, all cases of such differences occur in the autumn and winter months, September to February. As the seasonal rainfall is a total for the three months, the significant seasonal differences occur in the boundary between terciles 2 and 3 in winter and autumn and between terciles 1 and 2 in winter, with differences between 0·8 and 1·0 in. The winter and to a less extent the autumn climate has become wetter as between the two periods 1727 to 1872 and 1873 to 1970.

Table VI gives the tercile values for every month and season from 1727 to 1971. Modern years (since 1873) which would be classified one tercile lower according to boundaries determined from the period 1873 to 1970 are marked with an asterisk*, those which would be classified one tercile higher are marked with a dagger†. Table VII gives the wettest and driest months and seasons, and Table VIII gives the seasons with persistently dry or wet months, i.e. seasons with all 3 months terciles 1 or 3. As the probability of a tercile 1 month is 1/3, the probability of all 3 months of a particular season being tercile 1 is 1/27 so that over the 244 years some 9 of each of the seasons could be expected by chance to have all three months tercile 1. The numbers in Table VIII, which vary from 7 to 12, do not differ significantly from the expected frequency.

From Table VI the longest run of consecutive dry months is 8 from January to August 1741 and of wet months 7 from July 1960 to January 1961. For 17 months from April 1873 to August 1874 there were no wet months and for 26 months from July 1967 to August 1969 there were no dry months. These figures are about the chance expectation, which is about 7 or 8 consecutive months all with the same tercile and 22 to 23 months all with terciles 1 or 2, or with terciles 2 or 3. It may be concluded that, unlike central-England temperatures, there is no tendency for high or low rainfall terciles to persist from one month to the next.

TABLE VI—TERCILES OF MONTHLY AND SEASONAL ENGLAND AND WALES RAINFALL, 1727–1971

	J	F	M	A	M	J	J	A	S	O	N	D	W	S	S	A
1727	3	2	3	1	3	2	3	1	2	1	1	3		3	1	1
8	3	1	3	3	2	2	3	1	1	3	2	2	3	3	2	2
9	1	1	2	2	2	1	2	2	3	2	3	2	1	2	1	3
1730	1	2	3	1	2	3	2	1	2	2	2	1	1	3	1	2
1	1	1	1	2	1	3	1	1	1	1	1	1	1	1	2	1
2	1	2	2	3	3	1	1	1	1	3	1	2	1	3	1	1
3	1	2	3	2	1	3	1	3	1	1	1	3	1	1	3	1
4	1	3	3	1	3	3	1	3	1	2	1	3	3	3	2	1
5	2	2	3	2	2	2	3	2	2	1	3	2	3	2	3	2
6	3	3	3	1	2	1	3	1	1	3	1	3	3	1	3	1
7	1	3	3	2	1	1	1	3	3	1	1	2	2	2	3	1
8	2	1	2	1	2	3	1	1	2	2	1	1	1	1	1	1
9	3	3	1	3	3	2	2	2	2	1	2	2	3	3	2	1
1740	1	1	1	1	1	1	2	3	2	1	2	3	1	1	2	1
1	1	1	1	1	1	1	1	1	3	2	2	1	2	1	1	2
2	2	1	1	2	2	2	2	1	1	3	3	1	1	1	1	3
3	1	1	2	2	1	1	3	1	1	3	1	1	1	1	1	1
4	1	1	2	3	1	3	1	1	3	3	2	1	1	3	1	3
5	1	1	3	3	1	3	1	3	1	2	2	2	1	3	3	2
6	2	2	3	1	1	3	2	1	2	2	2	1	2	1	1	2
7	3	2	2	2	3	2	1	1	2	1	3	3	3	2	1	1
8	1	1	3	3	2	3	3	1	1	1	1	3	2	3	2	1
9	3	2	3	1	1	3	1	1	1	1	1	2	3	2	1	1
1750	1	2	1	3	1	2	1	1	1	1	2	2	1	1	1	1
1	3	1	3	3	3	2	3	1	2	1	2	1	2	3	3	2
2	3	2	2	2	3	3	3	2	1	1	1	2	2	2	3	1
3	2	3	1	2	1	1	2	3	1	2	3	3	3	1	3	2
4	1	1	2	2	2	3	3	2	1	1	1	3	2	2	3	1
5	1	1	2	3	1	2	2	3	2	1	3	1	2	2	2	3
6	2	1	2	3	1	3	2	3	2	1	1	1	1	3	3	1
7	2	1	3	3	2	1	3	3	1	1	2	2	1	3	3	1
8	1	3	2	1	1	2	3	2	2	1	1	2	2	1	3	1
9	1	1	3	3	2	3	1	3	2	2	1	1	1	3	3	1
1760	1	3	1	1	1	3	1	3	3	3	3	2	1	1	2	3
1	1	2	1	1	3	3	1	3	3	3	2	2	1	1	2	3
2	3	2	2	1	1	1	1	3	3	3	1	1	2	1	1	3
3	1	3	1	2	3	3	3	3	3	1	2	3	1	2	3	2
4	3	2	2	2	2	2	3	2	1	2	2	2	3	1	3	1
5	2	1	3	3	1	1	1	3	1	3	1	1	1	3	1	2
6	1	2	1	2	3	3	2	1	2	2	1	1	1	2	2	1
7	2	3	3	1	2	1	3	2	2	2	2	1	2	2	2	2
8	3	3	1	3	1	3	3	2	3	3	3	2	3	1	3	3
9	1	2	1	1	2	3	1	2	3	1	2	2	2	1	2	1
1770	1	2	2	2	2	3	1	1	2	2	3	3	1	2	2	3
1	2	1	2	1	1	1	1	3	2	3	1	2	2	1	1	2
2	2	3	3	1	2	3	1	2	3	2	3	1	2	2	2	3
3	2	2	1	2	3	1	1	2	3	3	2	3	1	3	1	3
4	3	3	2	2	2	2	2	2	3	1	1	1	3	2	3	1
5	2	3	2	1	1	2	3	3	3	3	2	1	2	1	3	3
6	1	3	2	1	1	3	2	3	3	1	2	1	2	1	3	2
7	1	2	2	2	3	3	3	2	1	3	2	1	1	2	3	2
8	2	1	2	1	3	2	3	1	1	3	3	3	1	2	2	3
9	1	1	1	2	2	2	3	1	3	2	2	3	1	1	2	3
1780	1	2	1	3	1	1	1	1	3	2	1	1	2	2	1	2
1	1	3	1	2	1	3	1	2	3	1	3	1	1	1	2	1
2	3	1	3	3	3	1	3	3	3	2	1	1	1	3	3	2
3	2	3	2	1	3	3	1	2	3	1	1	1	2	1	2	2
4	2	1	2	3	2	3	2	2	1	1	2	1	1	2	3	1
5	2	1	1	1	1	1	2	3	3	2	2	2	1	1	3	3
6	3	1	1	1	3	2	1	3	3	2	2	2	2	1	2	3
7	1	2	3	1	1	1	3	2	1	3	2	3	2	2	3	2
8	1	2	1	1	1	2	2	2	2	1	1	1	2	1	2	1
9	2	3	1	2	3	3	3	1	3	3	2	3	2	2	3	3
1790	2	1	1	2	3	2	2	2	1	1	3	3	2	1	2	2
1	3	3	1	2	1	1	3	2	1	2	3	2	3	1	2	2
2	2	1	3	3	3	2	2	3	3	2	1	3	2	3	3	2
3	2	3	2	2	1	1	1	2	2	1	2	2	3	1	1	1
4	1	3	2	3	2	1	1	2	3	3	3	2	2	2	1	3
5	1	2	2	2	1	3	1	2	1	3	3	2	1	1	2	2
6	3	2	1	1	3	1	3	1	2	2	1	1	3	1	1	1
7	2	1	1	2	3	3	2	3	3	1	2	3	1	3	3	3
8	2	1	1	1	1	1	3	2	2	2	2	1	2	1	2	3
9	2	3	1	2	2	1	3	3	3	2	2	1	2	1	3	3
1800	3	1	1	3	2	1	1	1	3	2	3	2	1	3	1	3
1	2	2	3	1	2	1	3	1	3	2	2	2	1	2	1	3
2	1	3	1	2	1	2	3	2	1	3	1	2	2	1	3	1
3	2	2	1	2	2	3	1	1	1	1	3	3	2	1	1	1
4	3	1	2	2	2	1	2	2	1	3	3	1	3	3	2	2
5	2	2	2	2	2	2	2	2	1	1	1	2	1	1	2	1
6	3	2	2	1	1	1	3	3	2	1	3	3	3	1	3	2
7	1	2	1	1	3	2	1	1	2	1	3	1	2	2	1	2
8	1	1	1	3	2	1	2	2	2	3	2	1	1	1	2	2
9	3	2	1	3	2	2	2	3	3	1	1	2	3	1	2	1
1810	1	2	3	1	2	1	3	3	1	2	3	3	1	2	2	3
1	1	2	2	2	3	2	2	1	1	2	2	2	3	3	2	2
2	1	3	3	1	3	3	2	1	1	3	2	1	2	3	2	2
3	1	3	1	1	3	2	2	1	2	3	2	1	1	2	1	2
4	2	1	2	3	1	2	2	2	1	3	3	3	1	2	2	2
5	1	2	3	2	3	2	1	2	2	2	1	2	2	3	2	2
6	2	2	2	2	2	2	3	1	2	2	2	3	2	2	3	2
7	2	2	2	1	3	3	3	3	1	1	2	3	3	2	3	1
8	3	2	3	3	2	1	1	1	3	2	3	1	3	3	1	2
9	3	3	2	3	3	2	1	1	2	1	1	3	2	3	1	1
1820	2	2	1	2	3	2	2	2	2	2	1	2	2	2	2	1
1	2	1	3	3	2	1	2	2	3	2	3	3	1	3	1	3
2	1	2	3	3	2	1	3	1	1	3	3	1	3	3	2	3
3	2	3	2	2	2	2	3	3	2	3	1	3	2	2	3	2
4	1	2	3	2	2	3	1	2	3	3	3	3	2	3	2	3
5	1	1	2	2	3	2	1	2	2	2	3	3	2	3	1	3
6	1	3	2	1	1	1	1	1	3	2	2	2	2	1	1	2
7	2	1	3	1	3	1	1	2	2	3	1	3	1	3	1	3
8	3	2	1	3	2	2	3	2	2	1	1	3	3	3	3	1
9	1	1	1	3	1	3	3	3	3	1	1	1	1	2	3	2
1830	1	2	1	3	3	3	2	3	3	1	3	1	1	3	3	2
1	2	3	3	2	1	2	2	2	3	3	2	3	2	3	2	3
2	1	1	2	2	2	3	1	3	1	3	3	2	1	2	3	2
3	1	3	2	3	1	3	1	2	2	2	2	3	3	1	2	2
4	3	1	2	1	1	2	3	2	1	1	1	1	3	1	3	1
5	1	3	3	1	3	2	1	1	3	3	2	1	1	3	1	3
6	2	2	3	3	1	2	2	1	3	3	3	2	1	3	2	3
7	2	3	1	2	1	1	2	2	1	2	2	2	3	1	2	1
8	1	2	2	1	2	3	2	2	2	2	3	1	1	1	2	2
9	2	2	3	1	1	3	3	2	3	2	3	2	1	1	3	3
1840	3	2	1	1	3	2	2	1	3	1	3	1	3	1	1	2
1	2	2	2	2	3	3	2	3	3	3	3	2	1	2	3	3
2	2	2	3	1	2	2	2	1	2	1	3	1	2	2	1	3
3	2	2	1	3	3	2	2	3	1	3	2	1	2	3	3	2
4	2	3	3	1	1	2	2	2	2	2	3	1	1	1	2	2
5	2	1	2	1	2	2	2	3	2	2	2	3	1	2	3	2
6	3	1	2	3	2	1	2	3	1	3	1	1	2	3	2	2
7	2	2	2	2	3	2	1	1	2	3	2	3	1	3	1	2
8	1	3	3	3	1	3	2	3	3	3	1	3	3	3	3	3
9	2	2	1	3	3	1	2	1	3	2	1	2	2	3	1	2
1850	1	2	1	3	2	1	3	2	2	1	2	1	2	2	2	1
1	3	1	3	2	1	2	2	2	1	2	1	1	2	2	2	1
2	3	2	1	1	2	3	2	3	3	3	3	3	3	1	3	3
3	3	1	2	3	1	3	3	2	2	3	1	1	3	1	3	2
4	2	1	1	1	3	2	2	1	1	2	1	2	1	1	1	1
5	1	2	2	1	2	3	3	1	1	3	1	1	1	1	3	2
6	2	2	1	3	3	2	1	3	2	1	1	2	1	2	2	1
7	3	1	2	3	1	2	2	3	2	3	1	1	2	2	2	2
8	1	1	1	3	2	1	2	2	2	2	1	2	1	2	1	1
9	1	2	2	3	1	2	2	2	3	2	2	2	1	2	2	3
1860	3	1	3	1	3	3	2	3	2	2	2	3	3	3	3	2
1	1	3	3	1	1	2	3	1	2	1	3	1	2	1	2	2
2	2	1	3	2	3	3	2	2	2	3	1	2	1	3	2	2
3	3	1	1	1	1	3	1	2	3	2	2	1	2	1	2	3
4	1	2	3	1	2	1	1	1	2	1	2	1	1	2	1	2
5	3	3	2	1	3	1	2	3	1	3	3	1	2	2	3	3
6	3	3	2	2	1	2	2	3	3	1	2	2	3	1	2	3
7	3	2	3	3	2	1	3	1	2	2	1	1	3	3	2	1
8	3	2	3	2	1	1	1	3	2	2	1	3	2	2	1	2
9	3	3	2	2	3	1	1	1	3	1	2	3	3	3	1	2

TABLE VI—*continued*

	J	F	M	A	M	J	J	A	S	O	N	D	W	S	S	A
1870	2	2	2	1	1	1	1	1	1	3	1	2	2	1	1	2
1	2	2	2	3	1	3	3	1	3	2	1	1	2	2	2	2
2	3	3	3	3	2	3	3	2	3	3	3	3	3	3	3	3
3	3	2	3	1	2	2	2	2	2	2	1	1	3	2	2	1
4	2	2	2*	2	1	1	1	2	3	2	2	2	1	1	1	3
5	3	2	1	1	2	3	3	1	3	3	3	1	3*	1	3	3
6	1	3	3	3	1	2	1	2	3	2	3	3	2*	3*	1	3
7	3	2	3	3	3	1	3	3	2	2	3	2	3	3	3	3
8	2	2	1	3	3	3	1	3	2	2	3	2*	2*	3	3	3*
9	2	3	1	3	3	3	3	3	2†	1	1	1	3*	2	3	1
1880	1	3	2	2	1	3	3	1	3	3	2	3	1	1	3	3
1	1	3	3	1	2	3	2	3	2	2	3*	3	3*	2	3	2
2	2	2	2	3	2	3	3	2	2	3	3	3	2	3	3	3
3	3*	3	1	1	2	3	2	1	3	2	3	1	3	1	2	3
4	3	2	2	2*	1	1	3	1	2	1	1	2	2	1	1	1
5	2	3	2	2	3	2	1	1	3	3	2	1	3*	2	1	3
6	3	1	3	2	3	1	3	1	2	3	2	3	1	3	1	3*
7	2	1	2	1	2	1	1	1	2	1	2	2*	2	1	1	2
8	1	1	3	2	1	2	3	2	1	1	3	2*	1	3*	3	2
9	1	2	3	3	3	1	2	3	2	3	1	1	1	3	2	1
1890	3	1	2	1	2	2†	2	2	1	1	3	1	2*	2*	3	1
1	2*	1	2	2	3	2	2	3	2	3	2	3	1	2	3	3
2	1	2	1	1	2	3	2	3	2†	3	1	1	2	1	2	3*
3	2*	3	1	1	1	1	2	1	1	2	2	2	2	1	1	1
4	2	3	2	2	2	2	3	2	1	3	3*	2	3	2	3	2
5	3	1	3	2	1	1	3	2	1	3	3	2	2*	1	2	2
6	1	1	3	1	1	2	1	1	3	3	1	3	1	1	1	3
7	2*	3	3	3	1	3	1	3	3	1	2	3	3	3	2	1
8	1	2	1	2	3	2	1	2	1	3	2	2	2*	2	1	2
9	3	2	1	3	3	1	1	1	2	2	2	2	3	3*	1	2
1900	3	3	1	1	2	2†	1	3	1	2	2	3	3	1	2	2†
1	1	1	3	2	1	2	2	2	1	1	2	3	2	2	1†	1
2	1	1	2	2	3	2	1	2	1	2	2	2	2	2	2	1
3	3*	2	3	2	3	2	3	3	3	3	1	2*	2	3	3	3
4	3*	3	2	2*	3	1	2	2	1	1	1	2*	3*	2	1†	1
5	1	1	3	3	1	3	1	3	1†	1	3	1	1	3	2	2
6	3	2	2	1	3	2	1	1	1	3	3*	2	2	2	1	3*
7	1	2	2*	3	3	3	1	2	1	3	2	3	1	3	2	2
8	1	2	3	3	2	1	2	3	2	1	1	2*	2	3	2	1
9	1	1	3	2	1	3	3	2	2	3	1	3	1	3	3	2

	J	F	M	A	M	J	J	A	S	O	N	D	W	S	S	A
1910	3*	3	1	3	2	2	2	3	1	2	3	3	3	2	3	2
1	1	2	2	2*	1	2†	1	1	2	2	3	3	2	1	1	2
2	3	2	3	1	2	3	3	3	1	2	2	3	3	2	3	2
3	3	1	3	3	2	1	1	1	2	2	2	1	3*	3	1	2
4	1	3	3	1	2*	2	3	1	1	1	3	3	1	3*	2	1
5	3	3	1	1	2	1	3	1	1	1	2	3	3	1	2	1
6	1	3	3	2	2	2	1	2	1	3	3	2	3	3	2	3*
7	2*	1	2	2	2	2	2	3	1†	3	1	1	1	2	3	2
8	3*	2	1	2	2	1	3	1	3	1	2*	3	2*	1	2	3
9	3	2	3	2	1	1	1	2	1†	1	2	3	3	3	1	1
1920	3	2	3	3	3	2	3	1	2	1	1	2	3	3	2	1
1	3	1	2	1	2*	1	1	3	1	1	1	2	2*	1	1	1
2	3	3	2	3	1	1	3	3	2	1	1	3	3	2	3	1
3	2*	3	2	2	2	1	2	3*	2	3	2	3*	3	2	1	3
4	3*	1	1	3	3	2	3	3*	3	3	2	3	2	3	3	3
5	2	3	1	3	3	1	2	2	3	2	2	3*	3	3	1	2
6	3	3*	1	3	2	3	2	2	1	2	3	1	3	2*	2	3
7	2	3	3	2	1	3	3	3	3	2*	3*	2	2*	2	3	3
8	3	2	3	1	1	3	1	2	1	3	3	2	3	2	2	3*
9	1	1	1	1	2	1†	2	2	1	3	3	3	1	1	1	3
1930	3	1	2	3	2	1	3	3	3	2	3	3*	3	3	3	3
1	2	3	1	3	3	3	3	3	2	1	3	1	3*	3	3	2
2	2	1	2	3	3	1	3	1	2†	3	1	1	1	3	1	3
3	2	3	3	1	2	2	1	1	2	2	1	1	2	2	1	1
4	2	1	3	3	1	1	1	2	2	2	1	3	1	3*	1	1
5	1	3	1	3	1	3	1	1	3	3	3	2	3	2*	1	3
6	3	3*	2	2	1	3	3	1	2†	1	3*	2	3	1	3	2
7	3	3	3	3	3	1	2	1	2	2	1	3	3	3	1	1
8	3	1	1	1	2	2	2	2	1	3	3	3	3*	1	2	3
9	3	2	2	3	1	2	3	2*	1	3	3	1	3	2*	3	3
1940	2	3	3	2	1	1	3	1	1	2	3	2*	3*	2	1	3
1	3*	3	3	1	2	1	2	3	1	2	2	1	2	3*	2	1
2	3	1	2	1	3	1	2	2	2	2	1	3*	1	3	1	1
3	3	1	1	1	3	2	1	2	2	2	1	1	3	1	1†	2
4	2	1	1	2	1	2	2	2	3	3	3	2*	1	1	2	3
5	2	3*	1	1	2	2	2	2	2	2	1	3*	2	2*	2	1
6	2	3	1	2*	3	3	2	3	3	1	3	3*	3	2*	3	3
7	2	2	3	3	2	2	2	1	1	1	2	2	2	3	1	1
8	3	2	1	2	2	3	1	3	2	2	1	3	3	1	3*	1
9	1	1	2*	2	2	1	1	1	1	3	3*	2	2*	2	1	3

	J	F	M	A	M	J	J	A	S	O	N	D	W	S	S	A
1950	1	3	1	3	2	1†	3	3	3	1	3	2*	3*	2	3	3
1	3*	3	3	3	3	1	1	3	2†	1	3	3*	3	3	2	3
2	2	1	3	2	2	2	1	3	3	2	3*	2	2	3	1	3*
3	1	2	1	3	2	2	3	2	2	2*	2*	1	1	2	2	1
4	2*	3	3	1	3	3	2	3	2†	3	3	2	1	2	3	3
5	2	2	2	1	3	3	1	1	1	2	1	3	2	3	1	1
6	3	1	1	1	1	2	3	3	2†	1	1	3	3*	1	3	1
7	2	3	2	1	2*	1†	3	3	3	2	1	2	3	1	3	2
8	2	3	2	1	3	3	3	3*	3	2	1	3*	3	2*	3	2
9	3*	1	2	3	1	1	2	1	1	2	3	3	2*	2	1	1
1960	3	3*	2	2*	1	1†	3	3	3	3	3	3	3	1	3	3
1	3	2	1	3	1	1	2	2	2	3	1	2	3	1	1	2
2	3	1	2*	3	2	1	1	3	3	1	2*	2*	2	2	1	1
3	1	1	3	3	2	3	1	3	2	1	3	1	1	3	2	2
4	1	1	3	2	2	3	1	1	1	1	1	2	1	3	1	1
5	3*	1	3	2	2	2	3	2	3	1	3*	3	2*	3*	2	2
6	1	3	1	3	2	3	2	3	1	3	2	3	3	3	3	2
7	2*	3	2	2*	3	1	2	2	3	3	2	2	3*	3	1	3
8	2	2	2	2	3	3	2	3	3	2	2	2	2*	3	3	3
9	3*	2	3	2	3	2	2	2	1	1	3	2	2	3	2	1
1970	3	3*	2	3	1	1	2	2	2	1	3	1	3	2	1†	3*
1	3	1	2	2	2*	3	1	3	1	1	2	1	1	2	3	1

Note : Modern years (since 1873) which would be classified one tercile lower according to boundaries determined from the period 1873 to 1970 are marked with an asterisk*; those which would be classified one tercile higher are marked with a dagger†.

TABLE VII—WETTEST AND DRIEST MONTHS AND SEASONS IN PERIOD 1727 TO 1970

Wettest months	J	F	M	A	M	J	J	A	S	O	N	D
Year(s)	1948	1923 1833	1947	1756	1773	1860	1758	1737	1918	1903	1852	1914
Rainfall (in)	7·0	6·0	6·8	5·6	5·7	5·9	7·3	7·6	7·2	8·3	8·1	8·0
Driest months												
Year(s)	1766	1890	1742	1938 1912 1817	1844	1925	1825	1742 1747	1743 1754	1781	1945 1748	1799 1788 1780
Rainfall (in)	0·3	0·1	0·1	0·3	0·3	0·1	0·3	0·4	0·2	0·5	0·8	0·5

Wettest seasons	Winter	Spring	Summer	Autumn
Year(s)	1915	1782	1763 1912	1852
Rainfall (in)	17·4	12·4	15·9	17·9
Driest seasons				
Year	1964	1741	1800	1748
Rainfall (in)	3·3	1·9	2·9	4·4

Note : 1 in = 25·4 mm.

TABLE VIII—SEASONS WITH ALL 3 MONTHS TERCILES (a) 1 OR (b) 3

	Winter		Spring		Summer		Autumn	
(a) All 3 months tercile 1								
	1731	1808	1740	1798	1732	1869	1731	1834
	1743	1858	1741	1863	1741	1870	1733	1904
	1744	1964	1760	1893	1780	1887	1749	1921
	1745		1785	1956	1800	1899	1754	1964
			1788		1818	1913	1805	
					1826	1949		
(b) All 3 months tercile 3								
	1774	1910	1751	1889	1763	1912	1760	1852
	1791	1915	1782	1920	1829	1957	1768	1872
	1869	1926	1792	1931	1879	1958	1794	1875
	1883	1960	1877	1951			1824	1935
							1836	1944
							1841	1960

Climatic variations. As well as the trend in temperatures and rainfall in the winter half year, Tables II and VI also reveal fluctuations in the frequency of the high or low quintiles or terciles. For example, the 25 Januarys ending in January 1787 are distributed amongst the five temperature classes as follows :

T_1	T_2	T_3	T_4	T_5
10	5	6	2	2

whilst the 25 Januarys ending in January 1939 are distributed :

T_1	T_2	T_3	T_4	T_5
2	1	5	7	10

Table IX gives for January the 25-year periods with a maximum number of cases of temperature in quintiles 1 or 2 or in quintiles 4 or 5. (T_{12} means temperature in either quintile 1 or quintile 2) and also the 25-year periods with a maximum number of cases of rainfall totals in tercile 1 or in tercile 3. Table IX shows a tendency to alternating warm and cold periods with an interval of about 70 years between successive warm periods. The rainfall

TABLE IX—25-YEAR PERIODS WITH MAXIMUM NUMBER OF TEMPERATURES IN QUINTILES 1 OR 2 AND 4 OR 5 AND OF RAINFALLS IN TERCILES 1 AND 3 FOR JANUARY

Period		Temperature quintiles (number of cases)			Period		Rainfall terciles (number of cases)		
		T_{12}	T_3	T_{45}			R_1	R_2	R_3
1714–1738	Warm	7	1	17					
1763–1787	Cold	15	6	4	1757–1781	Dry	13	8	4
1782–1806	—	12	5	8	1782–1806	—	5	13	7
1807–1831	Cold	17	2	6	1807–1831	Dry	14	7	4
1851–1875	Warm	7	5	13	1851–1875	Wet	5	6	14
1874–1898 up to 1879–1903	—	10	5	10	1887–1911	Dry	12	5	8
1915–1939	Warm	3	5	17	1918–1942 and 1919–1943	Wet	2	8	15
1940–1964	Cold?	10	7	8	1944–1969	—	6	11	8

shows an approximation to alternating wet and dry periods also with an interval of about 70 years between successive wet periods. The rainfall variations are mostly in step with the temperature variations, the warm periods being wet and the cold being dry.

Table X gives similar information for July. Temperature oscillations with a period of about 70 years again occur but these are largely out of phase with the January temperature oscillations. For July rainfall the oscillations are less definite but the period is about 50 years.

TABLE X—25-YEAR PERIODS WITH MAXIMUM NUMBER OF TEMPERATURES IN QUINTILES 1 OR 2 AND 4 OR 5 AND OF RAINFALLS IN TERCILES 1 AND 3 FOR JULY

Period		Temperature quintiles (number of cases)			Period		Rainfall terciles (number of cases)		
		T_{12}	T_3	T_{45}			R_1	R_2	R_3
1702–1726	Cold	14	4	7					
1726–1750	Warm	5	6	14	1729–1753	Dry	12	7	6
1759–1783	Warm	4	7	14	1775–1799	Wet	7	7	11
					1803–1827	—	9	10	6
1839–1863 and 1840–1864	Cold	17	1	7	1828–1852 and 1829–1853	—	4	16	5
					1854–1878	—	9	9	7
1863–1887 to 1865–1889	—	11	1	13	1871–1895	Wet	5	8	12
					1889–1913	Dry	11	9	5
1907–1931	Cold	13	4	8	1917–1941 and 1918–1942	Wet	6	8	11
1932–1956 and 1933–1957	Warm	7	3	15	1940–1964 to 1942–1966	—	9	9	7

Table XI gives 25-year periods with a maximum number of cases of temperature in quintiles 1 or 2 or in quintiles 4 or 5 and Table XII gives 25-year periods with a maximum number of cases of rainfall in tercile 1 or in tercile 3 for all months and seasons. These are taken from the most recent 150 years.

TABLE XI—25-YEAR PERIODS* (ENDING AT YEAR(S) NAMED) WITH MAXIMUM NUMBER OF TEMPERATURES IN QUINTILES 1 OR 2 AND 4 OR 5 FOR EACH MONTH AND SEASON

			T_{12}	T_3	T_{45}			T_{12}	T_3	T_{45}			T_{12}	T_3	T_{45}			T_{12}	T_3	T_{45}
December	1970	?	8	6	10	1934	Warm	6	4	15						1893	Cold	12	5	8
January	1964	Cold?	10	7	8	1939	Warm	3	5	17	1898–1903	?	10	5	10	1875	Warm	7	5	13
February	1971	?	10	5	10	1927–28	Warm	7	4	14	1909–10	?	12	3	10	1885	Warm	7	2	16
March	1957–63	Warm	5	8	12											1888–89	Cold	14	4	7
April	1961	Warm	8	0	17	1925–26	Cold	15	5	5						1878	Warm	6	6	13
May	1971	?	7	8	10	1931–34	Warm	6	7	12	1900	Cold	15	1	9					
June	1954	Warm	5	9	11	1929–31	Cold	12	8	5	1900	?	12	2	11	1886	Cold	13	6	6
July	1956–57	Warm	7	3	15	1931	Cold	13	4	8						1887–89	?	11	1	13
August	1955–56	Warm	6	3	16	1924	Cold	16	4	5						1880	?	9	4	12
September	1969–71	Warm	7	2	16	1928	Cold	13	6	6										
October	1971	Warm	3	4	18											1896	Cold	15	4	6
November	1961–64	Warm	3	5	17	1925	?	11	3	11	1908–09	Warm	8	2	15	1875	Cold	17	2	6
Winter	1970/71	?	7	8	10	1934/35	Warm	3	4	18						1893/94	Cold	12	4	9
Spring	1961	Warm	4	3	18						1909	Cold	14	7	4					
Summer	1955–57	Warm	4	5	16	1931	Cold	17	3	5						1878–80	?	5	11	9
Autumn	1969–71	Warm	3	1	21											1894	Cold	14	6	5

* Taken from the most recent 150 years

TABLE XII—25-YEAR PERIODS* (ENDING AT YEAR(S) NAMED) WITH MAXIMUM NUMBER OF RAINFALLS IN TERCILES 1 AND 3 FOR EACH MONTH AND SEASON

			R_1	R_2	R_3			R_1	R_2	R_3			R_1	R_2	R_3			R_1	R_2	R_3
December						1930	Wet	3	7	15						1858	Dry	13	8	4
January	1968	?	6	11	8	1942–43	Wet	2	8	13	1911	Dry	12	5	8	1875	Wet	5	6	17
February	1965–66	?	11	5	9	1936–37	Wet	8	4	13	1909–10	Dry	11	8	6	1885	Wet	2	12	11
March						1948	Dry	12	5	8	1918–20	Wet	6	6	13					
April	1960	?	10	8	7	1937	Wet	6	7	12	1915–16	?	8	10	7					
May	1969	Wet?	4	12	9						1919	?	8	10	7					
June	1968–69	?	9	6	10	1942	Dry	14	5	6						1853	Wet	4	11	10
July						1941–42	Wet	6	8	11	1913	Dry	11	9	5	1895	Wet	5	8	12
August	1964–71	Wet	5	7	13	1949	?	8	11	6	1912	Wet	5	10	10					
September	1968	Wet	6	8	11						1917	Dry	17	5	3	1833	Wet	2	12	11
October	1970	Dry	11	8	6											1865	Wet	5	9	11
November						1950–52	Wet	8	2	15						1895–96	Wet	6	7	12
Winter						1938/39 1939/40	Wet	4	5	16	1908/09 1909/10	?	8	11	6	1883/84 1884/85	Wet	4	10	11
Spring	1969–71	Wet	5	9	11						1920–21	Wet	5	8	12	1897–98	?	10	7	8
Summer						1949	Dry	12	6	7	1907–08	Dry	11	9	5	1852–53	Wet	5	9	11
Autumn						1946–47	Wet	7	4	14	1921–22	Dry	10	11	4	1883	Wet	3	9	13

* Taken from the most recent 150 years

Table XI shows that for the most part the three winter months and the winter season vary out of phase with other months, being at the maximum frequency for T_{45} around the period 1911–35 when most other months were at a maximum frequency for T_{12}. The recent decline in the frequency of T_{45} months in the winter months has to date, only produced 25-year periods with distributions close to the expected (average) frequency of 10 T_{12}, 5 T_3 and 10 T_{45}. All other months are close to or have just passed a 25-year period with a maximum frequency of T_{45} months. This is especially so in the case of autumn — no less than 21 out of the last 25 autumns have been classified T_4 or T_5.

For rainfall, the picture is less clear cut. Rainfall oscillations in January are largely in phase with February but July oscillations are out of phase with August.

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REVIEWS

Problems of satellite meteorology, edited by I. P. Vetlov and G. I. Morskoi. 245 mm × 173 mm, pp. v + 102, *illus.* (translated from the Russian by Israel Program for Scientific Translations, Jerusalem), Keter Press Ltd, 15 Provost Road, London, NW3 4ST, 1970. Price: £3·80.

There are many problems of satellite meteorology and meteorologists may find the title of this book something of a misnomer. We are told on the cover leaf however that 'this collection contains articles pertaining to processing, interpretation and use of data collected by meteorological satellites for weather analysis and prediction. It is intended for specialists in synoptic and dynamic meteorology, and workers of operational units of hydrometeorological services'.

Of the 11 articles by different authors, 4 are limited by their geographical context and will have only casual interest for most meteorologists. These are :

T. P. Popova; The cloudiness structure in cyclones in southern European U.S.S.R.
I. A. Alekseeva; The intertropical convergence zone in the eastern Pacific from meteorological satellite observations.
I. R. Egorova; Features of atmospheric fronts in the southern hemisphere from satellite observations.
E. P. Dombkovskaya; Relationship between cloud masses observed from a satellite and their precipitation zones.

The first of these shows how satellite television photographs can be used to interpret the evolution of depressions originating over the Black Sea and the Caspian Sea and subsequently affecting the U.S.S.R. It is similar to case studies prepared elsewhere and has local interest only. The paper by I. A. Alekseeva examines the spatial structure of the cloud field in the eastern part of the tropical Pacific with the aid of satellite observations during 1967, the approach being purely climatological.

Many practising forecasters are somewhat disappointed with the interpretation of radiation data from satellites as a means of analysis. The paper on atmospheric fronts in the southern hemisphere deals with this problem but is limited in value primarily because of the sparse coverage of orthodox meteorological data which are a necessary background to satisfactory interpretation. The author considers some features of fronts in the South Pacific for March–April 1967 using satellite radiation data from the METEOR system. Average and extreme values are presented of the radiation characteristics in the region of the front for two latitudinal belts (27–45°S and 45–60°S) and for a number of specific frontal zones.

The article by E. P. Dombkovskaya examines the relationship between precipitation and cloud cover as deduced from satellite pictures, the data applying to the European U.S.S.R. A list of rules is given relating precipitation and cloudiness, e.g. 'As a rule, precipitation zones occupy a relatively small proportion of cloud masses. In 87·2 per cent of the cases the total precipitation-occupied area was less than one-third of the cloud mass, while in 97·7 per cent it was less than half'.

Most meteorologists will find strange the use of the word 'nephelometer' instead of 'nephanalysis', presumably due to mistranslation.

The use of visual satellite data as a means of specifying the wind field is dealt with in two papers. The first, by L. A. Anekeeva, 'Use of cloud data obtained by meteorological satellites for an objective analysis of the wind field', is based on a statistical analysis of the relation between wind and cloud bands in large spiral cloud vortices. The data refer to the period March 1966–March 1967 over the Soviet Union, Western Europe and the north-eastern Atlantic. On page 4, in the reference to Bykov's programme, there is of course no vertical component as stated. The other paper by T. D. Dzyubenko and A. M. Tsar'kova deals with the determination of the jet-stream axis from satellite cloud data. The study uses data from the North Atlantic, Europe, west Siberia and central Asia and reaches the following conclusions :

(a) The jet stream is seen on TV cloud photographs in 46 per cent of the cases. The jet-stream sections most frequently seen are those located in the forward part of the 'altitudinal' trough.

(b) The cloud mass is usually located on the warm side of the jet-stream axis and its boundary in 72 per cent of the cases coincides with this axis.

(c) The average wind speed at the jet-stream axis, traced on TV photographs, ranges from 44 to 52 m/s; the wind shear per 100 km perpendicular to the jet-stream axis is 7·6 m/s at the cold side and 6·2 m/s at the warm side.

M. Nazirov, in the paper 'Shadow on satellite photographs as a source of information on the height of cloud', deals with the application of correction factors depending on the distance between the shadows and the sub-satellite point.

The most practical paper, by K. P. Vasil'iv, 'Use of meteorological satellite data as a navigational aid', describes methods for interpreting TV pictures of sea ice and the difficulties encountered in this work. As might be expected, this is well done. The less satisfactory part of the paper deals with the

significance of cloud-vortex photographs for 'gale-swell' zones in the ocean, intended as an aid to ship routeing.

'A qualitative analysis of satellite infra-red data' by E. V. Dzybenko and V. V. Puchkov examines the possibility of determining the radiative-surface temperature and altitude of an upper cloud boundary using METEOR infra-red data in the 8–12 μm range. It is claimed that a quantitative analysis of infra-red information from METEOR satellites can be carried out in 'operative times'. Another investigation of satellite infra-red data by V. G. Boldyrev, D. M. Sonechkin, V. I. Tulupov, and I. S. Khandurova determines correlation functions and spectral densities of the intensity of outgoing radiation over the spectral range 0·6–0·8 μm using measurements of the COSMOS-45 satellite. The results confirm the presence of a deep mesoscale minimum in the spatial spectrum of reflected radiation, and of a maximum corresponding to the characteristic dimensions of synoptic formations (cyclones and anticyclones).

The last paper in the book, by G. I. Morskoi, is a review article on studies of large-scale vertical motion in the atmosphere and is perhaps valuable for its extensive bibliography.

As might be expected in a book of this kind, the reproduction of satellite photographs is in general rather less than satisfactory and this deficiency is made worse by the quality of the paper, which is not sufficiently opaque. The main interest for most meteorologists is the information afforded by an independent approach to problems already treated in a somewhat different fashion elsewhere — primarily in the U.S.A.

T. H. KIRK

Random functions and turbulence. International series of monographs in natural philosophy, Volume 32, by S. Panchev. 257 mm × 183 mm, pp. xii + 444, *illus.,* Pergamon Press Ltd, Headington Hill Hall, Oxford, 1971. Price: £7·00, $18·75.

This book is based on a Russian edition first published in 1967 and is primarily intended to serve as an introduction to the statistical theory of turbulence. Thus the first two parts are devoted to a comprehensive description of the theory of random functions and their use in the investigation of turbulence. The final part considers the application of this theory to some selected topics; namely small- and large-scale atmospheric turbulence and numerical weather analysis and prediction. There is also an appendix written by Professor S. K. Kao of the University of Utah, which discusses large-scale Lagrangian aspects of turbulence in the atmosphere.

The author is professor of meteorology at the University of Sofia, Bulgaria, and as expected, his treatment of the topic is based on both the Western and Russian approaches — though there is a strong bias towards the latter. This should make the book quite useful to a research worker as it provides a fairly comprehensive description of the techniques and theories used by the Russians, though in later editions it would be helpful if the section on the modified Kolmogorov Hypothesis were extended. However, this book cannot really be recommended as an introduction to the subject as it is highly mathematical and the 'physics of the problem' tends to be rather obscured by the Russian approach which is based on structure and correlation functions. Before starting to refer to this book the student would probably be better advised

to consult a book such as Hinze's* which is based more on the spectral approach to this topic. Interestingly enough, Panchev himself tends to underline this advice, as in Chapter 6 he admits that the spectral method gives a clearer physical insight into the subject.

The final sections of the book present some quite interesting results, though again, there is a strong emphasis on the Russian work. This is not really a disadvantage as many of the significant advances in these fields have originated from that part of the world and it will be useful to have a summary of this work available.

There are a number of misprints in the present edition and the reader needs to keep a critical eye on the equations, though here most of the errors relate to their numbering. The index could also be improved somewhat.

Despite its faults this book should serve as quite a useful reference for workers in this and allied fields provided they are willing to spend a little time familiarizing themselves with its layout and the notations used.

C. J. READINGS

OFFICIAL PUBLICATIONS

The following publications have recently been issued :

British Rainfall 1964. (London, HMSO. Price: £10.)

This publication provides a comprehensive summary of the rainfall of 1964 with discussion of both the incidence of rainfall and its variation from place to place, based on data from about 6000 observers. It contains numerous tables, graphs and maps.

The 'General Table of Rainfall' forms Part I of the volume and contains annual and monthly rainfall totals and the rainfall of the wettest day where daily values are available. Part II discusses the main characteristics of the year and contains sections dealing with monthly, annual and seasonal rainfall, spells of rainfall deficiency and excess, frequency distribution of daily amounts of rainfall, heavy falls on rainfall days and in short periods, also Penman estimates of potential evapotranspiration. Part III contains the annual report of the 'Snow Survey of Great Britain' for the season 1963–64 by R. E. Booth, and 'Potential Evapotranspiration Data, 1964' by F. H. W. Green.

Marine climatological summaries for the Atlantic Ocean east of 50°W and north of 20°N. (London, HMSO. Price: £6.)

These summaries are part of a series of similar summaries covering the oceans of the world, which are to be published by nine countries, including the United Kingdom, in accordance with an internationally agreed scheme sponsored by the World Meteorological Organization. This first summary is for 1964 and it is intended eventually to publish similar summaries for each of the years from 1961 onwards.

The information in the tables relates entirely to observations made aboard ships on passage, or at ocean weather stations by observers of countries co-operating in the scheme. The results included in the tables depend upon large numbers of observations and production of the tables was facilitated by processing the data by means of programmes written for the KDF9 computer at the Meteorological Office, Bracknell.

* HINZE, J. O.; Turbulence. London, McGraw-Hill, 1959.

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